POLSKA AKADEMIA NAUK · KOMITET NAUK GEOLOGICZNYCH

PAŃSTWOWE WYDAWNICTWO NAUKOWE . WARSZAWA

acta geologica polonica

Vol. 29, No. 2 Warszawa 1979

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The Tumlin Sandstone (Holy Cross Mts, Central Poland): Lower Triassic deposits of aeolian dunes and interdune areas

ABSTRACT: Recognition of the Lower Triassic sedimentary environment of the Tumlin Sandstone (Holy Cross Mts, Central Poland) has been based mainly on sedimentary features observed in large quarry exposures. The Tumlin Sandstone, c 100 m thick, is characterized by a very large-scale high-angle cross-stratification which is thought to have been formed on lee-slopes of aeolian dunes, mainly as a result of a grainfall process. The cross-strata usually pass downdip into subhorizontal, laminated deposits accumulated over the interdune area. These deposits contain in places subordinary intercalations formed by ephemeral waters, both flowing (lenses of structureless sandstones) and stagnant (mudstone layers). The cross-stratified sandstones with the underlying subhorizontal deposits form, as a rule, thick layers separated by extensive erosional bounding surfaces that are subhorizontal, and sligthly concave upward over a considerable distance. Their windward parts usually display a wide scoop-like forms resultant from a wind erosion; the details of its formation remain however unclear. The sedimentary environment of the Tumlin Sandstone is to be regarded as a field of transversal dunes migrating northward due to prevailing unidirectional winds. This field occupied part of a midcontinental basin situated at the axis of the maximum subsidence of the Danish-Polish Trough.

INTRODUCTION

The Tumlin Sandstone is characterized by a very large-scale cross--stratification which makes it readily distinguishable from other Lower Triassic (Buntsandstein) sediments exposed over the Mesozoic margins of the Holy Cross Mts, Central Poland. For many years this feature has provoked much interest in the sedimentary conditions of this unit, but no detailed investigations have as yet been specifically undertaken. Pawlica (1920) in discussion of the heavy minerals assemblage was the first to suggest an aeolian origin of the Tumlin Sandstone. Senkowiczowa & Ślączka (1962, p. 323) considered the deposits as probably deltaic, but they also admitted that a very large-scale cross-stratification might have been formed in coastal dunes. However, in the following years Ślączka & Roniewicz (1971) expressed an opinion that the Tumlin Sandstone exposed in the Ciosowa quarry had been laid down by flowing water. Taking account of the measured dips of cross-laminae and the characteristics of cross-stratified units, Gągol & Karpiniec (1974, p. 449) concluded that most of the sedimentological premisses indicate its aeolian origin.

The divergent opinions presented above incited the present authors to detailed sedimentological investigations of the Tumlin Sandstone. Most of the field work was carried out in 1975—1976 and the preliminary results were presented (Gągol 1976) at the 48th Annual Meeting of the Geological Society of Poland.

In this paper the authors present the evidence of the aeolian origin of the Tumlin Sandstone; the origin of the very large-scale cross-stratification is attributed to the deposition on lee slopes of dunes. Water-laid deposits are of minor importance, and they occur sporadically among the wind-blown deposits of the interdune areas.

Acknowledgements. The authors are pleased to record their thanks to Dr. S. Gąsiorowski, Dr. G. Haczewski, Dr. S. Kwiatkowski, Dr. S. J. Porębski, and Dr. E. Turnau for reading the manuscript and for instructive discussion. Thanks are extended to Dr. E. Piekarska and M. Kuleta, M.Sc., for their significant contribution on petrography of the sandstones. Special credit must be given to M. Doctor, M.Sc., for his help in taking photos of the thin sections and specimens.

GEOLOGICAL SETTING

The sediments described in the present study as the Tumlin Sandstone make up the upper part of the informal lithostratigraphic unit, distinguished by Senkowiczowa & Ślączka (1962), named the Tumlin Beds and assigned to the lowermost part of the Middle Buntsandstein (*see* Senkowiczowa 1970, 1973).

The pre-Rhöt Lower Triassic deposits in the north-western margin of the Holy Cross Mountains are mainly sandstones and mudstones. Their thickness attains to 1000 m. The exposures of the Tumlin Sandstone are limited to a relatively short and narrow latitudinal belt; good exposures which permit a detailed investigation of the sedimentary features are accessible only in the five big quarries: Sosnowica, Tumlin-Pieniężna, Tumlin-Gród, Wykień, and Ciosowa (see Text-fig. 1). It should be stressed that the method of stone exploitation used in the quarries (splitting off large plates without explosives) is well suited for the examination of stratification surfaces and of bounding surfaces which separate individual sedimentary units, as well as of vertical cross-sections which are visible on the exposed walls. (*cf.* Pls 1—4).

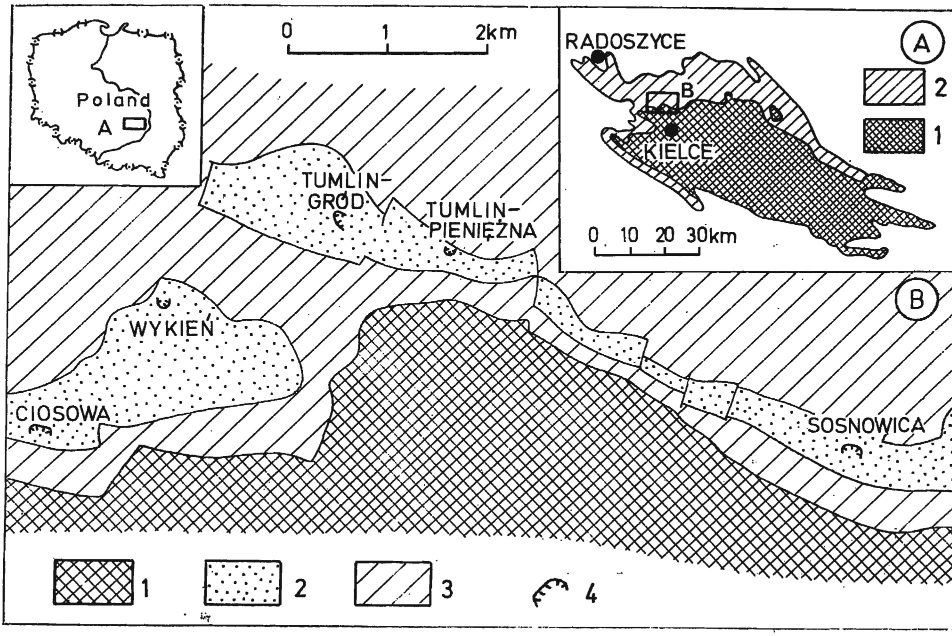


Fig. 1. Sketch maps showing general geological setting (**A**) and location of investigated quarries (**B**)

Map **A**: *1* — Palaeozoic rocks of the Holy Cross Mts; *2* — Lower Triassic rocks
Map **B**: *1* — as in map *A*; *2* — Tumlin Sandstone; *3* — Buntsandstein rocks other than the Tumlin Sandstone; *4* — quarries

The thickness of the Tumlin Sandstone amounts at least to 60 m in the investigated zone. Its lower and upper boundaries cannot be observed due to the spatial distribution and character of the exposures. The regional geological investigations indicate (*see* Senkowiczowa & Ślączka 1962; Senkowiczowa 1970, 1973) that the Tumlin Sandstone is underlain by a sedimentary complex about 300 m thick, devoid of fossils and consisting of sandstones and mudstones with sporadically dispersed crystals of gypsum, anhydrite and dolomite, and with intercalations of gravels. A 90 m thick complex of fine-grained sandstones, mudstones and claystones overlies the Tumlin Sandstone, and such fossils as *Gervillea murchisoni*, *Estheria* sp., and fish remnants were found in its upper part.

The data obtained from the borehole Radoszyce (Dembowska 1957) situated 25 km NW from Tumlin (*see* Text-fig. 1) demonstrate that the Tumlin Sandstone extends beneath the surface, and it attains the thickness of 105 m. Rocks of that type have been found neither in exposures nor in boreholes in the north--eastern and south-western margins of the Holy Cross Mountains (*cf.* Samsonowicz 1929; Senkowiczowa & Ślączka 1962; Senkowiczowa 1970, 1973).

Within the area under investigation the Tumlin Sandstone has diverse tectonic dips. The analysis of some of the bounding surfaces and beds, which were assumed to be horizontal at the time of deposition, permitted determination of the dip angle in respective quarries as follows: Sosnowica — 18/11 (direction of dip and angle of dip, both values in degrees), Tumlin-Pieniężna — 340/10, Tumlin--Gród — no tilt, Wykień — no tilt(?), Ciosowa — 10/10. It should be stressed, however, that due to difficulties in precise determination of the originally level surface, the values denoting the dip angle may be erroneous $\pm 2°$.

GENERAL LITHOLOGY

The rocks exposed in investigated quarries are almost exclusively medium- and fine-grained sandstones, mostly laminated. Subordinately they contain lenticular intercalations practically devoid of stratification, called further in this paper "the structureless sandstones". Mudstones occur only occasionally as not extensive and invariably very thin intercalations.

The dominating sedimentary structure is the very large-scale cross-stratification; its cross-strata are often of a high-angle type. There are some layers, however, where a subhorizontal stratification prevails, many of them passing upwards into very large-scale cross-stratified units. Bounding surfaces are common, both diversely inclined and subhorizontal ones.

Two important sedimentary associations can be distinguished in the Tumlin Sandstone if we accept as a criterion the inclination of depositional surfaces to an originally level plane. The first of them, association *A*, is composed of deposits characterized by high, moderate and partly low angles of dip; The other, association *B*, includes the remaining deposits, *i.e.* those with horizontal and very gently inclined stratification. As both associations pass into each other, their boundaries often must be determined arbitrarily. Association *A* is represented by laminated sandstones only, while association *B* includes lenses of structureless sandstones and mudstone intercalations. As regards details, types of stratification of the latter association are much more diversified. Also the grain-size distribution in association *B* is more varied. Association *B* generally contains more pelitic material which is accumulated in the form of extremely thin coatings on the surface of sandy laminae or, sporadically, it is individualized as discrete laminae rarely attaining a few millimetres in thickness. The laminae are usually discontinous; they form drapes within wave ripples or are preserved as flakes.

Most sandstones are red; their hue falls under the groups *5 R, 10 R, 5 YR*, the lightness usually ranges from 4 to 6, and the saturation oscillates between 2 and 4 (*cf.* Godward 1970); the colours *5 R 4/4* and *5 R 7/2* are dominating, darker laminae being usually *5 R 3/4*; mundstones are mostly reddish-brown (*10 R 3/4*).

PETROGRAPHIC DESCRIPTION

The sandstones consist of mono- and in less quantities of polycrystal quartz (79—88%); rock fragments occur only sporadically and are represented by mudstones, quartzitic sandstones and siliceous rocks. Feldspars, usually strongly weathered, and micas occur in minute quantities (0.3% on an average), mostly in deposits of association *B*. The ground mass occurs in the form of cement and matrix; it consists of quartz overgrowths and clayey-ferruginous binding mass (6—12%). Iron oxides are dispersed in the matrix and form minute coatings on quartz grains on the inner side of quartz overgrowths. The average content of

Fe_2O_3 is 1.07%. The content of carbonates is characteristically small: CaO — 0.05%, MgO — 0.22%.

The heavy mineral assemblage (Pawlica 1920) consists of apatite, tourmaline, basaltic amphibole, zoisite, and of smaller quantities of zircon, rutile, amphibole, hyperstene, garnet, magnetite and ilmenite. All grains of heavy minerals are well rounded.

TEXTURE

The grain-size distribution was analysed using photographs of thin sections. Two hundred grains were measured in every thin section.

The sandstones are medium- or fine-grained, moderately or moderately well sorted (Table 1 and Text-fig 2). Grains of diameter 2—3 mm are rare and occur in rocks of the association *B* only; this association has also a higher percentage of grains smaller than the sand size.

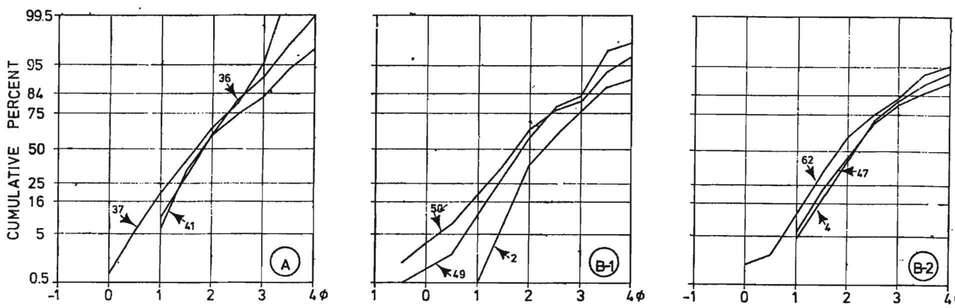


Fig. 2. Grain-size distribution curves

A — sandstones of association *A*; **B-1** — laminated sandstones of association *B*; **B-2** — structureless sandstones of association *B*; Measurements in thin section, *cf.* Table 1

Table 1

Statistical parameters of grain-size distribution of main sandstone types; thin section data

Sediment type	Sample No.	*Md*	M_z	S_I	%<4 phi
Laminated sandstone, association *A*	41	1.80	2.07	0.85	2.5
Laminated sandstone, association *A*	36	1.68	1.84	0.70	0.5
Laminated sandstone, association *A*	37	1.68	1.72	0.80	—
Laminated sandstone, association *B*	2	2.22	2.38	0.82	8.6
Laminated sandstone, association *B*	49	1.85	2.00	0.85	0.2
Laminated sandstone, association *B*	50	1.71	1.90	1.14	4.1
Structureless sandstone, association *B*	47	2.05	2.18	0.94	9.2
Structureless sandstone, association *B*	62	1.80	1.97	0.93	4.6
Structureless sandstone, association *B*	44	2.11	2.32	0.75	6.6

Sphericity and roundness were determined in the 0.5—0.25 mm grade, by visual comparison with the standard table presented by Krumbein & Sloss (1963, Figs 4—10, p. 111). The mean values of roundness for individual thin sections range from 0.33 to 0.46, and of sphericity — from 0.45 to 0.53 (*cf.* Text-fig. 3).

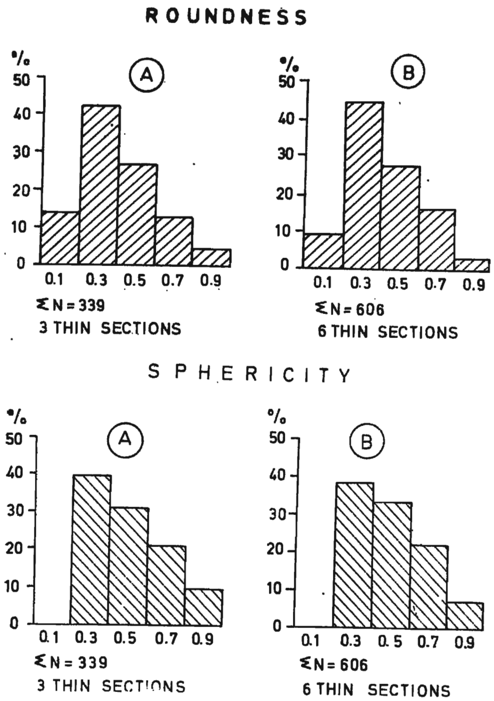


Fig. 3
Histograms of roundness and sphericity
A — sandstones of association *A*;
B — sandstones of association *B*

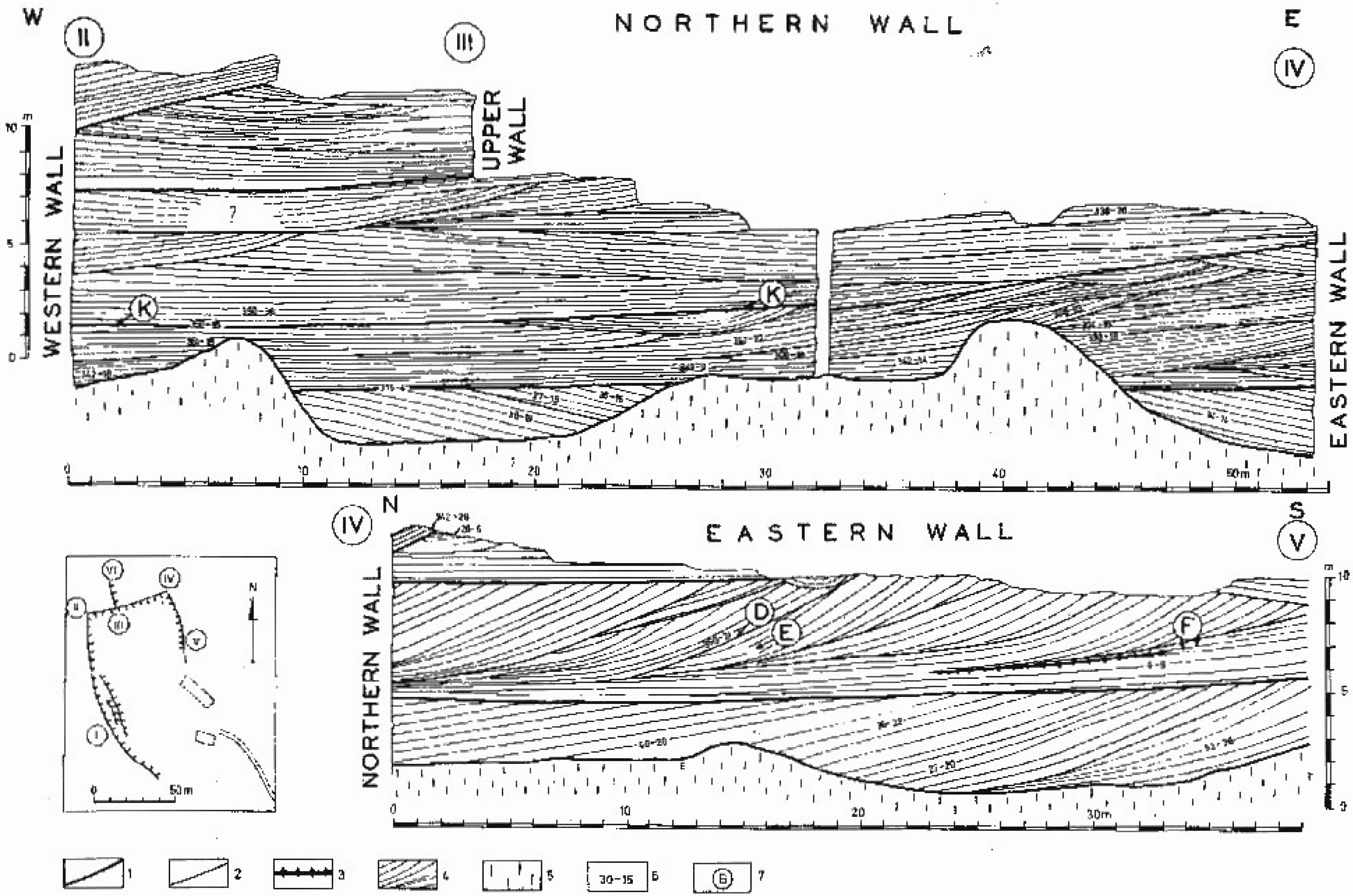
Scanning electron microphotographs of the quartz grains revealed a common occurrence of upturned plates, usually modified by solution and precipitation (Pl. 24, Figs 1 & 2); surface textures of this kind are characteristic of the aeolian environment (*see* Krinsley & Doornkamp 1973; Margolis & Krinsley 1974). It should be noted that in many grains their original surface is completely obscured by regeneration overgrowths.

GROSS INTERNAL GEOMETRY

The spatial arrangement of the Tumlin Sandstone is generally hierarchical, with sedimentary units of several orders (*see* Text-figs 4—7 and Pls 1—4). These units are individualized in different ways, depending on the orientation of the observed section, so that their precise distinction is not possible in each case. The main units of the first order are named compound sets in this paper, and the second order units — the sets. The latter usually consist of cross- and/or horizontal laminae (referred to an originally level plane). In some cases bundles of laminae are distinguished within the sets; they are named the intrasets.

The inclination of bounding surfaces of the first and second order units is variable, ranging from a high-angle (up to 36°) to a horizontal

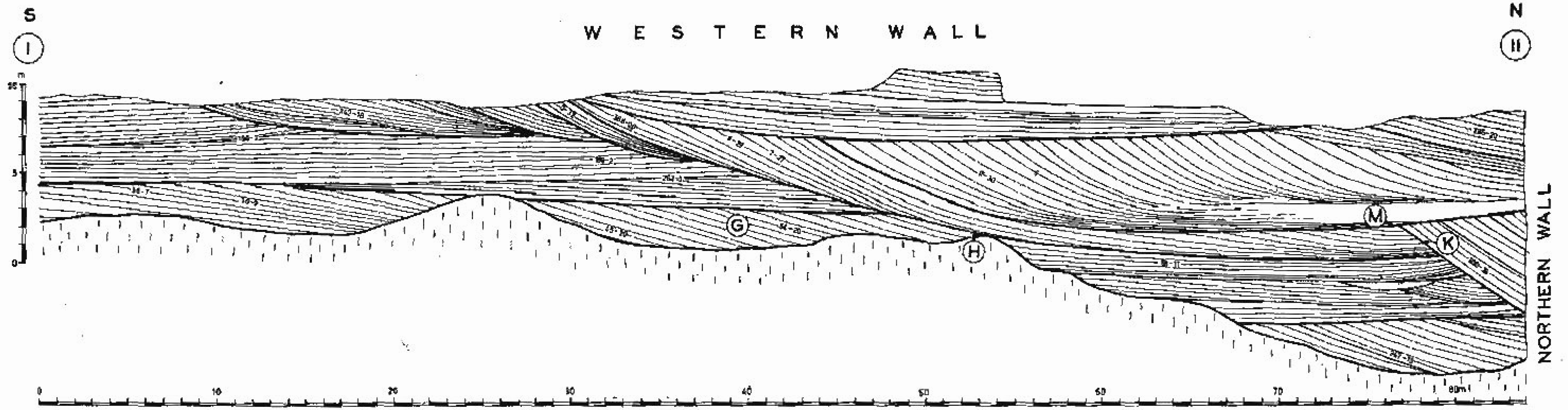
Sketches of northern and eastern walls of quarry Tumlin-Gród; Inset shows schematic plan of quarry with the reference points (I-VI)



1 — main bounding surface; 2 — additional bounding surface; 3 — layer with mud-cracks; 4 — selected strata; 5 — rubble; 6 — direction of true dip and angle of true dip (both values in degrees);

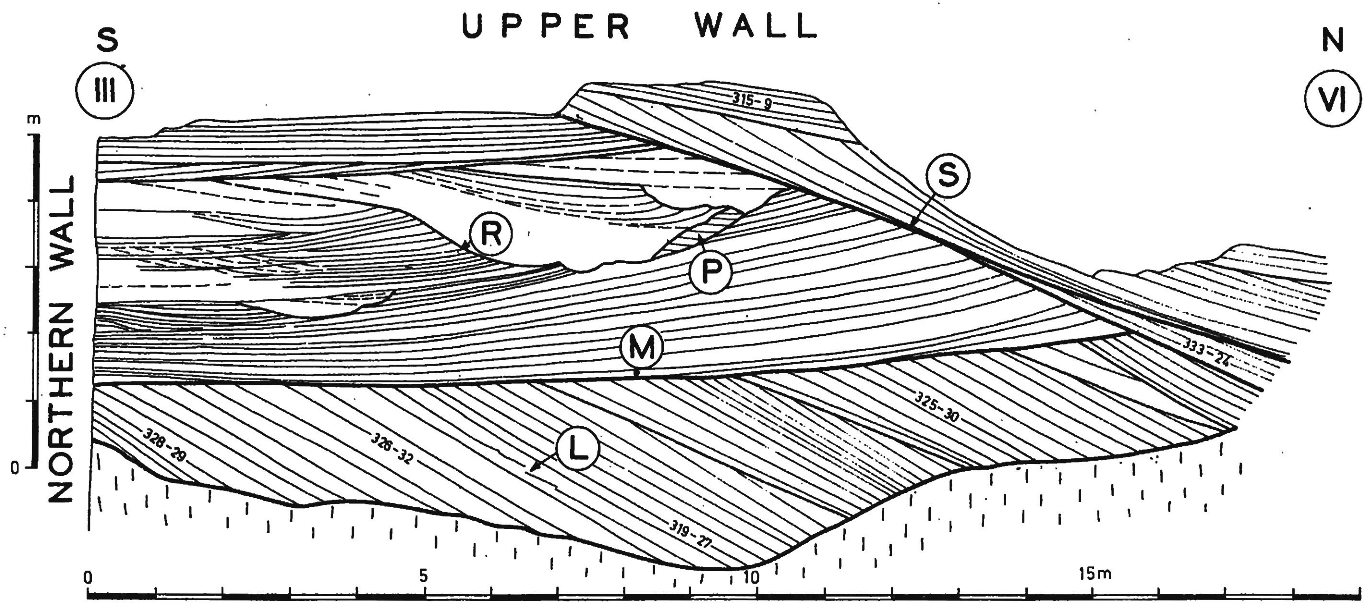
7 — reference points mentioned in text or in explanation of plates 1—4: D — aeolian ripples on cross-stratum surface; E — interfingering of associations *A* and *B* (see Pl. 13, Fig. 2); F — water level terraces (*see* Pl. 19, Fig. 1); K — inclined main bounding surface, part of giant scoop-like surface (*cf.* Text-fig. 5)

Sketch of western wall of quarry Tumlin-Gród; for location and general explanation, see Text-fig. 4



G — aeolian ripples on surfaces of cross-strata; H — giant scoop-like surface; K — steeply inclined part of giant scoop-like surface (cf. Text-fig. 4); M — subhorizontal part of main bounding surface (cf. Text-fig. 6)

Sketch of upper wall of quarry Tumlin-Gród; for location and general explanation, see Text-fig. 4



L — deformations of cross-laminae in form of overthrusts (*see* Pl. 8, Fig. 2); **M** — subhorizontal main bounding surface (*cf.* Text-fig. 5 and Pl. 6, Figs 1 & 2); **P** — slided and rotated block at bank of erosional channel; **R** — deformations at bank of erosional channel (*see* Pl. 14, Fig. 1) position. The bounding surfaces are commonly erosional and bevel or truncate discordantly the underlying deposits. The laminated sediments overlying directly the bounding surfaces are usually parallel to them or inclined at a very low angle, independent of the inclination of the bounding surface itself (*see* Text-fig. 7; Pl. 1 and Pl. 12, Fig. 1).

The compound sets are very thick, usually subhorizontal layers of a relatively great lateral extent; they can be traced for tens of metres, often throughout the whole quarry. Main bounding surfaces which separate the compound sets are generally smooth, subhorizontal and slightly concave upwards. In some cases the windward endings of these surfaces can be observed: they are concave upwards and rapidly steepening towards the contact with higher main bounding surface (*see* Text--figs 5 & 7 and Pl. 2). The shape of these endings resembles very wide scoops and such parts of the main bounding surfaces are thereby called "the giant scoop-like surfaces". Their maximum dip is 36°, but usually it is smaller. The observed thickness of the compound sets attains 7 m

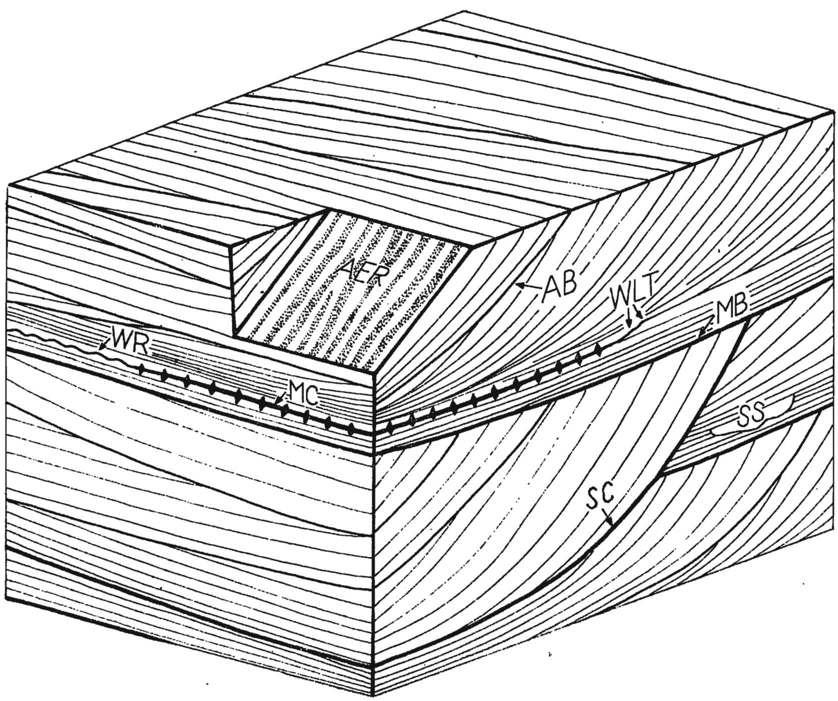


Fig. 7. Idealized blockdiagram showing gross internal geometry of the Tumlin Sandstone

MB — main bounding surface; **AB** — additional bounding surface; **SC** — giant scoop-like surface; **AER** — aeolian ripples; **WR** — wave ripples; **MC** — mud cracks; **WLT** — water-level terraces; **SS** — lens of structureless sandstone; for further explanation *see* Text-fig. 4

and usually ranges between 3 and 5 metres. In some places it gradually falls to zero due to the bevelling of a compound set by a lower bounding surface of the younger compound set.

In a typical compound set, individual sets have a similar spatial arrangement (*see* Text-figs 4—7 and Pls 1—3). They display a form of inclined wedges, thinning and flattening downwards in the direction of the dip. Additional bounding surfaces separate the sets. Some of those surfaces extend from the upper to lower bounding surfaces of their parent compound set. Nevertheless, often in the upper part of the compound set the additional bounding surfaces, observed in *ac* section (i.e. parallel to the general dip of cross-strata) are almost rectilinear; in such cases upper parts of the sets are generally tabular planar (*cf.* Pl. 5, Fig. 1). In the *ab* (horizontal) section the discussed surfaces observed over tens of metres are almost rectilinear (Pl. 6, Figs 1 & 2) or only inconspicuosly bent dipward and only sporadically undulated.

Generally, the bounding surfaces of sets are steepest in the upper part of the compound sets where their dip reaches as much as 36°, often exceeding 25°. The angle gradually decreases downslope. In many cases the boundaries are tangential to the lower bounding surface of the parent compound set. On the other hand, the bounding surfaces of sets frequently happen to approach the lower surface and continue subparallel to it for several tens of metres or more (*see* Text-figs 4 & 5). In such cases the inclined sets pass laterally into horizontal ones. In a number of such cases cross-laminae can be traced to continue as horizontal ones (*see* Pl. 2).

The inclined bounding surfaces of sets visible in *ac* section usually dip at a slightly smaller angle than the bevelled cross-laminae of the lower set, and opposite cases are rare (*see* Text-fig. 6 and Pl. 1). Many additional bounding surfaces are not discernible in this section, but may be seen in *bc* section and in the plan (compare eastern and northern walls in Text-fig. 4; *see also* Text-fig. 7). In such cases the cross-laminae of the adjacent sets have similar dip angles, but differ in the dip direction; the differences are usually smaller than 10° and only exceptionally exceed 15°.

The maximum thickness of individual sets usually ranges from a few tens of centimetres to 2—3 metres.

Between the inclined sets solitary troughs occur sporadically (*see* Text-fig. 4, eastern wall), filled symmetrically or asymmetrically with curving laminae.

The maximum dip of cross-laminae in individual sets rarely attains 36°, normally ranging between 20° and 30°. Within individual compound sets the dip directions observed in the exposure usually vary from several degrees up to 30°.

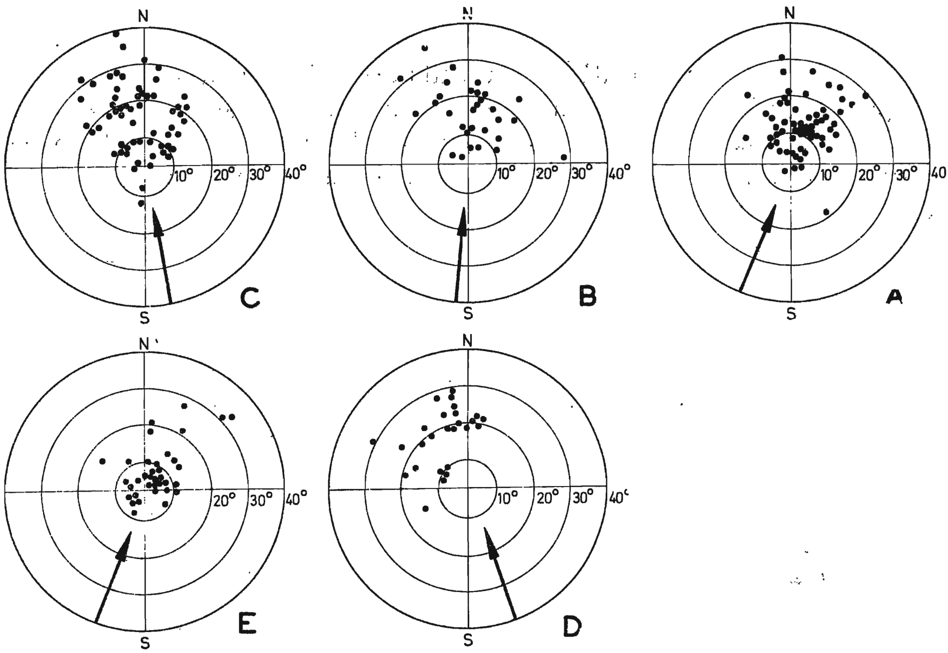


Fig. 8. Distribution of dip attitudes

Polar net, upper hemisphere; original orientation. Quarries: **A** — Sosnowica; **B** — Tumlin-Pieniężna; **C** — Tumlin-Gród; **D** — Wykień; **E** — Ciosowa

Table 2

Vector resultant and consistency ratio of dip directions

Quarry	Dips ⩾ 15°			All dips		
	Number of measurements	Consistency ratio	Direction of vector resultant	Number of measurements	Consistency ratio	Direction of vector resultant
Sosnowica	28	0.80	22°	65	0.67	21°
Tumlin-Pieniężna	20	0.86	4°	30	0.84	5°
Tumlin-Gród	33	0.90	349°	57	0.75	353°
Wykień	24	0.90	341°	30	0.86	334°
Ciosowa	7	0.87	19°	36	0.52	29°

In each quarry the inclination of cross-laminae was measured in several compound sets. The compiled diagrams indicate that the degree of dispersion of the dip directions is inversely proportional to the value of the dip angle (Text-fig. 8). The directions of strata whose inclination exceeds 15° have a relatively small dispersion. In individual quarries the consistency ratios assessed for these strata (using the method of Curray 1956) are high and the resultant vectors have similar directions in all the quarries (Table 2 and Text-fig. 8).

LAMINATION OF SANDSTONES

The basic, thinnest stratification units are called laminae throughout this paper, without determining the maximum thickness (*cf.* Campbell 1967). The laminae are mesoscopically marked, mainly due to differences in colour. Those consisting of relatively fine grains are often darker, but this is not the rule.

Table 3

Characteristics of lamination

	Association *A*	Association *B*
Length of laminae	very long (metres and tens of metres)	very long, locally short
Thickness of laminae	from tenths of millimetre to 15 cm	from tenths of millimetre to a few centimetres, thin and very thin laminae prevail
Lateral change in thickness of individual laminae	gradual downdip thinning	usually none, locally considerable
Distinctness of laminae	good to poor	usually good
Grain-size differences between adjoining laminae	insignificant	insignificant, rarely great
Bounding surfaces of laminae	smooth prevail	smooth, locally disturbed by numerous small protuberances

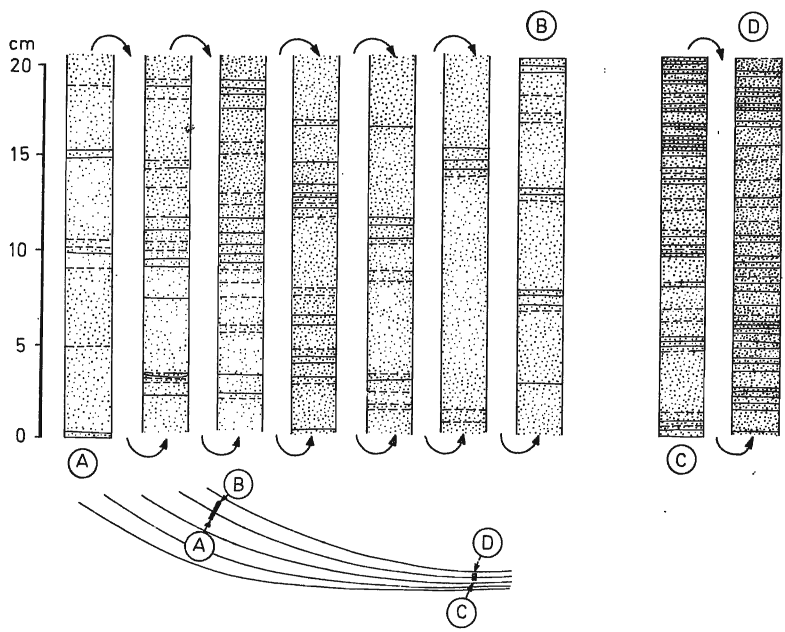


Fig. 9. Lamination in sandstones of association **A** (profile *A-B*) and of association **B** (profile *C-D*)

Indistinct boundaries of laminae are marked with dashed line

The examination of thin sections reveals that the boundaries of laminae are formed as a result of rapid (Pl. 22, Fig. 1) or gradual (Pl. 22, Fig. 2) change in grain size; sometimes these boundaries are additionally marked by a change in the type of cement or matrix (Pl. 22, Fig. 3 and Pl. 23, Fig. 1).

The sandstone lamination in associations *A* and *B* is generally similar, but some differences are found (Table 3), mainly in the thickness and distinctness of the particular laminae (Text-fig. 9).

ASSOCIATION *A*

Thick and very thick laminae with indistinct boundaries are most typical (Pl. 7, Fig. 2). They are intercalated with relatively thin, well defined laminae, usually grouped in bundles (*see* Text-fig. 8). A downdip flattening of whole sets is usually accompanied with gradual thinning of individual laminae, especially of the thicker ones (*see* Pl. 2). The wedging out, as well as the gradual disappearance and appearance of laminae are rare. Consequently, most cross-laminae can be traced in *ac* sections over considerable distances (*see* Pl. 2 and Pl. 7, Fig. 1). In *bc* sections most laminae extend for at least several metres. In one case only an erosional structure was observed in such section (Pl. 12, Fig. 2), and can be interpreted as a spoon-shaped depression formed in the upper part of a sand avalanche. It should be stressed that cone--shaped sandflow cross-strata as demonstrated by Hunter (1977, Figs 6 & 7) were not encountered.

The interfingering of avalanche deposits (which are usually represented by thick laminae in the aeolian sediments) with well laminated deposits at the toe of the dune lee-slope (for modern examples, see McKee & *al.* 1971, Figs 3b & 4b; McKee & Douglass 1971, Fig. 2; Hunter 1977, Figs 6c & 6d) was not observed in the Tumlin Sandstone. Only in one case inclined intrasets of cross-laminae were observed to interfinger with the deposits almost completely devoid of lamination (Pl. 13, Fig. 2); nevertheless, this case is exceptional and in no way typical of the Tumlin Sandstone.

Structures closely resembling the deformations by sand avalanching of lee-side laminae of modern aeolian dunes described by McKee & *al.* (1971) occur sporadically in association *A*. Prevailing among them are fuzziness or lack of distinctness of individual laminae, especially the thicker ones. Such laminae contrast with more distinct thin ones grouped in bundles. Warps (gentle folds; *see* Pl. 8, Fig. 1) and stretched laminae are rare. Overthrusts (Pl. 8, Fig. 2), break-apart laminae and structures resembling recumbent folds are very rare. Deformations visible on the parting surfaces of cross-strata are found in a few cases. They occur in the form of miniature steps oriented updip (Pl. 9, Fig. 2) or gentle elevations and depressions (Pl. 9, Fig. 1) resembling a relief of the sand-flow upper surface (*cf.* McKee & *al.* 1971, Figs 3d & 4d).

A few of the gently inlined parting (= lamination) surfaces exposed in the Ciosowa quarry were patterned by a specific linear microrelief, approximately parallel to the sedimentary dip of the cross-laminae. The origin of this relief is obscure, but it might result from sand avalanching.

ASSOCIATION *B*

In this association thin, sharply defined laminae grouped in bundles are prevailing (Text-fig. 9 and Pl. 13, Fig. 1); they are intercalated with subordinate thicker laminae (Pl. 11, Fig. 1). In the latter strata a subtle low-angle cross-stratification is visible. Such layers are regarded as subcritically climbing translatent strata with noticeable ripple-foreset cross-laminae (*sensu* Hunter 1977).

In places, individual laminae have an admixture of apparently coarser grains (0.5—1.5 mm) with occasional, still coarser grains up to 3 mm (*cf.* Pl. 20, Fig. 1). Such laminae are usually thin (few millimetres), and only exceptionally assume a form of relatively thick lenses (Pl. 11, Fig. 2).

The bulk of the sandstones is subhorizontally laminated, with great lateral continuity and regularity. In some layers, however, the regular lamination is interrupted by small-scale scour-and-fill structures, lenticular intercalations with low-angle cross-stratification and other structures, described below.

LENSES OF STRUCTURELESS SANDSTONES

Structureless sandstones occur in a form of elongated lenses of various size (*see* Pl. 1). Their thickness is in each case several times greater than that of the thickest laminae of the embedding sandstone; the thickness does not exceed 20—30 cm and only occasionally amounts to 1 metre. The lenses may be observed for several metres or tens of metres along their long axis.

Lower boundaries of the lenses are sharp. In the cross-section they usually have a fairly regular, concave upward outline resembling a bottom of an erosional channel. Bottoms of more extensive lenses are almost horizontal in some places, but secondary depressions, relatively deep, are locally encountered. The surrounding sediments are sometimes deformed at the erosional banks of channels. The deformation may occur in the form of a downward bending of the laminae (Pl. 14, Fig. 1) or of sediment lumps displaced along the inclined shear-planes (see *P* in Text-fig. 6). Isolated blocks of the laminated sediment are also found to be embedded in a mass of structureless sandstone, varying in size and orientation (Pl. 14, Fig. 2).

In some lenses, in their upper or lateral parts, there occurs a progressively more distinct lamination; this is mostly a low-angle cross-stratification (*see* Text-fig. 6 and Pl. 1). Other lenses seem to consist exclusively of the structureless sediment.

Tops of most lenses are horizontal and concordant with stratification of the surrounding deposit. The sandstone plates split off in the course of stone exploitation revealed that some lens tops are generally convex upwards and reveal smaller, irregular undulations (Pl. 15, Fig. 1) or a sublinear relief with distributary rill pattern (Pl. 15, Fig. 2).

The structureless sandstones do not differ significantly in their grain-size distribution from the subhorizontally laminated sandstones (*see* Table 1 and Text-fig. 2). No preferred grain orientation is discernible in thin sections (Pl. 23, Fig. 2).

The described features of the structureless sandstones, especially their occurrence within association *B* and the character of their bottom, do not permit their considering as deposits of dry sand-flows. It is also doubtful whether the lenses resultant from the process described by Peacock (1966) and Sanderson (1974), *i.e.* were formed by progressive deformation leading to complete disappearance of primary internal structures.

The present authors suggest that the lenses of structureless sandstones were deposited during episodic heavy rainfalls, when ephemeral streams flowed through interdune depressions, locally eroding their bottoms and almost immediately filling in the excavated channels. Due to homogeneity of the transported material, heavy loading of the streams and rapid water soaking in the substratum favoured deposition of structureless sand. It is also not unlikely that at least a part of the structureless sandstones was laid down by mass-flows. This assumption is corroborated both by the presence of "drowned" blocks, evidently transported and deposited by pasty-flows in a viscous medium, and by the occurrence of the irregularly bulbous upper bounding surfaces of some lenses, resembling a relief of water-saturated mass-flow deposits (*see* Carter 1977). The relief of these surfaces shows a striking similarity to a sand-flow formed on a dune margin after an episodic flood (*see* Fleming 1977, p. 75).

The lenses found on the upper wall of the quarry Tumlin-Gród (Text-fig. 6 and Pl. 1) are visible in a section approximately perpendicular to their long axis. They belong to several successive generations, and are thought to have been deposited in a narrow interdune depression oriented W—E. Its axis was gradually shifted to the north as a result of migration of the bordering dunes. Successive positions of the depression axis are marked by younger and younger erosional channels. The inclination of laminae in the upper part of channel-filling sediments reflects to some extent the shape of the interdune depression during its migration.

RIPPLES

Two classes of ripples are distinguished in the Tumlin Sandstone. They are referred to as aeolian and wave ripples on the features evidently indicative of their origin.

AEOLIAN RIPPLES

Ripples of this class are fairly frequently observed in association *A* on surfaces of the cross-strata. The ripple crests are distinguished from troughs by a lighter tone (Pl. 10) and in most cases are parallel to the dip of the cross-strata (*cf.* Text-fig. 7). These crests are straight to slightly curved, sporadically bifurcating, spaced out 7—25 cm apart, and 1—4 mm high. Most of the ridges are strongly flattened, which hinders determination of the original ripple indices. In some cases, however, the ripples are found to be asymmetrical. Individual ripple crests can be observed over a distance up to 4 m. Some of the ripple crests consist of sligthly coarser grains than the troughs. Cross lamination has never been observed in the ripples.

Ripples with a similar pattern and orientation are common on lee slopes of modern aeolian dunes (*see* McKee & *al.* 1971, Fig. 6c); some fossil examples have also been described (*e.g.* Walker & Harms 1972; Steidmann 1974; Sanderson 1974; Brookfield 1977). The origin of such ripples is probably related to sand transport across the dune face by lee-side eddies. The flattening of ripple crests observed in the Tumlin Sandstone may be due to deterioration of the ripples resulting from an increased wind force (*cf.* Bagnold 1941, p. 153; Sharp 1963). The explanation proposed by Steidmann (1974) for similar ripples in the Casper Formation of Wyoming appears more likely. According to this author, after wetting the dune surface ripple crests dry more rapidly than troughs and are more easily truncated by wind erosion.

Low relief, flat shape, and lack of internal structures substantiate interpretation of the aeolian origin of these ripples (*cf.* Tanner 1964; Sharp 1963; Walker & Harms 1972; Hunter 1977).

WAVE RIPPLES

Ripples of this class are encountered exclusively in deposits of association *B*, usually in the vicinity of or even in the continuity of mudcracked layers. In the cross-section they occur in the form of isolated trains among horizontally laminated sandstones.

Straight of slightly sinuous ripple crests are prevailing, while the bifurcations are rare (*see* Pl. 16, Fig. 2). The ripples are usually 5—8 cm apart, 7—11 mm high, the ripple index ranges from 5 to 8. They are symmetrical or slightly asymmetrical (Pl. 17, Fig. 2), their crests are always gently rounded. Chevron structures are visible in cross-sections of most ripples (Pl. 17, Fig. 1), bundled upbuildings are also common (Pl. 17, Fig. 3). Darker, mud-enriched laminae are encountered mostly in troughs, but they can also drape some adjacent ripples.

The presented characteristics correspond well with most features diagnostic of wave ripples, listed by de Raaf & *al.* (1977, pp. 457—459). The only apparent difference is that the Tumlin ripples are usually underlain by a flat surface. According to the present authors, this can be explained by the aeolian origin of the horizontally laminated deposits embedding the ripple trains.

In one case a layer of very fine sand, *c* 2 cm thick, was observed to contain symmetrical ripples built of form-concordant laminae. The observations and experiments of Reineck (1961) have shown that such ripples can also be wave-generated.

MUD CRACKS AND CURLED MUD FLAKES

Mudstone intercalations within the sandstones are usually dissected by polygonal network of mud cracks. The polygon diameters vary from a few to 30 centimetres. Due to the very small thickness of mudstone layers (from tenths of a millimetre to a few millimetres), the mud cracks are visible almost exclusively at parting surfaces parallel to the stratification. The mud-crack network usually appears as ridges on the upper surface (Pl. 16, Fig. 1), and the polygon surfaces are concave upward.

The mud-cracked laminae are often transformed into curled mud flakes. Some of these flakes are tube-like, almost completely closed, up to 5 cm in diameter. As a rule, they are not flattened. Layers full of curled mud flakes are observed on parting surfaces parallel to stratification (Pl. 18, Fig. 1) and on vertical cross-sections (Pl. 18, Fig. 2). The mode of preservation of these flakes indicates that they were buried by wind-blown sand in the same way as is observed in ephemeral ponds and wadi channels of modern sandy deserts (*see* Glennie 1970, pp. 52—53).

Mud cracks with downward concave polygons occur sporadically; their dimensions and network shape do not differ from those of normal mud cracks into which the former pass laterally (*see* Pl. 19, Fig. 1). In all observed cases the downward concave mud cracks occurred in very thin mudstone layers.

The mode of occurrence of the downward-concave mud cracks in the Tumlin Sandstone seems to refute the opinion that the origin of such structures is closely related to the salinity of water or sediments (for references and discussion *see* Picard & High 1973, pp. 116—120); on the other hand, it corrobates the conclusion of Shrock (1948, p. 203) that concave and convex polygons can be formed almost simultaneously on the same surface in the same mud and water. As regards their occurrence at the shore of an ephemeral pond (*see* Pl. 19, Fig. 1), it is unlikely that the downward concave polygons there observed were formed as a result of a more rapid dehydration of the lower part of the mud lamina, in the way suggested by Roniewicz (1965, pp. 213—214; *see also* Minter 1970).

REMNANTS OF AN EPHEMERAL POND WITH FOOTPRINTS

The only mudstone layer observed in the quarry Tumlin-Gród is exposed in the eastern wall (Text-fig. 4). It is very thin (a few millimetres) and can be traced over a distance of some ten metres. It rises gently southward and pinches out in the same direction. The thinning is accompanied with a decrease in mud-crack fissure width and in polygon diameter (Pl. 19, Fig. 1). Farther to the south, there extends a sandstone surface which is generally smooth excepting for two sets of horizontal microterraces whose morphology is characteristic of water-level marks (*see* Picard & High 1973). Very small wrinkle marks, strikingly similar to those described by Häntzschel & Reineck (1968), occur between the two sets (Pl. 19, Fig. 2).

The described surface, together with its terraced part, is covered with numerous shallow depressions, about 3 cm in diameter. They can be seen at regular intervals in the higher part of the surface; in this part prints of four sharp-ended toes are distinct in each depression, always oriented in the same direction (Pl. 19, Fig. 2). In the lower part, in the proximity of the mud cracks, the depressions become gradually indistinct.

The relief of footprints is not perfectly discernible, even in the best preserved forms, because remnants of the infilling material are still found in respective depressions. For this reason the prints have not as yet been determined, but presumably, they were left by a small reptile. The sandstone plate with the footprints is housed in the collection of the Institute of Geological Sciences, Polish Academy of Sciences in Cracow.

Position, lithology and sedimentary structures of the layer with mud-cracks point to a fossilized peripheral zone of an ephemeral pond in an interdunal flat. The investigated fragment of the pond adjoined a dune front advancing from the south. The pond might extend farther to the north, behind the zone with visible mud cracks. However, the deposits of the farther part of the pond, which had been exposed there for a longer time before they were buried by the advancing dune slope, were removed by deflation. Examples of a similar interfingering of deposits of ephemeral ponds with dune sands are reported from the Barun Goyot Formation in Mongolia (Gradziński & Jerzykiewicz 1974).

The presence of the microterraces situated succesively lower, indicates that water level in the pond was falling down (*cf.* Picard & High 1973, pp. 39—41). The footprints were left when the microterraces had already been formed. In the upper part of the exposed surface these traces were probably left on moist cohesive sand, while those situated in the lower part were pressed on the still wetter, almost saturated sand; in the latter case the margins of depressions became partly obliterated by liquefaction.

Similar exposures of fossilized pond shores, but without footprints, were observed in the Sosnowica quary.

ADHESION STRUCTURES

The structures considered by the present authors to be due to adhesion occur in subhorizontally stratified sandstones of association *B* and are most frequently observed in the deposits separating thin mudstone intercalations or horizons with wave ripples.

The adhesion structures appear on parting surfaces in the form of small knobs or swellings, 1—2 mm high, densely and irregularly spaced; in cross-section the sandstone reveals an irregular wavy lamination (Pl. 20, Figs 2 & 3). These structures are very similar to adhesion warts described by Reineck (1955). Among them there occur, here and there, slightly larger swellings with poorly visible cross-lamination, resembling adhesion ripples (*see* Reineck 1955; Reineck & Singh 1973). Adhesion warts and adhesion ripples are formed when dry sand is blown by the wind on a smooth, wet substratum. Glennie (1970, 1970) reported the occurrence of similar structures in interdune sabkhas, both fossil and modern ones.

Some of the rugged surfaces observed in the Tumlin Sandstone resemble the textured surfaces described by Picard & High (1973, pp. 132—134), effected by rain drops falling on loose sand.

GROOVES

Sets of small parallel grooves were observed at tops of sandstone strata in the deposits of the same type as those bearing the adhesion structures. The length of the grooves ranges from a few to ten centimetres, their width is about 2 mm, and the depth never exceeds 2 mm (Pl. 20, Fig. 1). Some of the grooves display relatively coarse (up to 3 mm) grains preserved at their endings, others terminate with small pits left by the grains removed by recent weathering.

The grooves are considered to be traces of coarser sand grains transported by a strong wind, left when the grains touched the surface of wet sand and glided over it. The movement of grains after impact might have been facilitated by the presence of a very thin film of water on the sediment surface.

TRACE FOSSILS

Biogenic structures are rare in the Tumlin Sandstone, and occur only in the deposits of association *B*, usually in the vicinity of mudstone intercalations. Apart from the footprints, a few traces of annelids(?) have been found (Pl. 21, Fig. 2). Irregular burrows filled with sand and having a few millimetres in diameter are more frequent (Pl. 21, Fig. 1). The burrows run across the laminae of muddy sandstone and in some places the sediment becomes strongly bioturbated. A few such burrows were found in troughs of the wave ripples. Radial structures, spreading from a central depression, that occur sporadically on sandstone surfaces (Pl. 21, Fig. 2) are also interpreted as being of a biogenic origin.

SEDIMENTOLOGICAL INTERPRETATION

The Tumlin Sandstone is regarded by the present authors as a dune field deposits including both deposits of dunes (association *A*) and of interdune areas (association *B*).

The assemblage of characteristic sedimentary features of association *A* includes:

1) great thickness (several metres) and large lateral continuity of individual main cross-stratified units;
2) relatively steep inclination of the cross-strata, amounting to 36°;
3) bevelling or truncation of the main sedimentary units by extensive bounding surfaces, which are subhorizontal or slightly concave upward over considerable distances;
4) occurrence of series of additional, inclined bounding surfaces within the main units; the surfaces bevel or truncate the underlying cross-laminae which are usually inclined at a higher angle than the bounding surfaces;
5) shape of individual, inclined sets of cross-laminae, tabular in the upper part and curved, wedge-like in the lower one;
6) very great length of individual cross-laminae;
7) relation of overlying laminae to the inclined bounding surfaces: the former are parallel or subparallel to the latter;
8) occurrence of ripples on surfaces of cross-strata; values of the ripple index are high and the ripples are subparallel to the dip direction of cross-strata;
9) presence of synsedimentary deformations indicative of sand avalanching;
10) predominance of grains of medium- and fine-sand grade, the insignificant percentage of smaller grains, and lack of grains coarser than sand-grade.

Sedimentary structures in association *A* are strikingly similar to those occurring in lee-slope deposits of modern aeolian dunes. The latter structures were described, *i.a.* by Land (1964), McKee (1966), McKee & *al.* (1971), Glennie (1970), and Hunter (1977). Similar structures were also found in their fossil counterparts (Shotton 1937, Thompson 1968, Glennie 1970, Horne 1971, Walker & Harms 1972, Steidmann 1974, Gradziński & Jerzykiewicz 1974). The whole assemblage of sedimentary structures may be considered diagnostic of and thus relevant to the origin of association *A* on lee-slopes of aeolian dunes.

Textural features of the described deposits, especially their grain-size distribution, are consistent with the postulated origin of association *A*.

It should be noted that the relatively low degree of roundness is not inconsistent with such origin. Although many dune sands consist of well rounded quartz grains, in others most grains are subrounded to subangular; the latter feature is observed both in modern sediments (Norris & Norris 1961, p. 612; Glennie 1970, Figs 134 & 135) and in fossil ones, *e.g.* in the Rock Point and the Luckachuai Members of the Wungate Sandstone (Harshbagger & *al.* 1957, pp. 10—11), as well as in the Chuska Sandstone (Wright 1956; Poole 1962, p. 147).

Depositional processes of the cross-strata need further discussion. Steep inclination of cross-laminae, approaching the angle of repose, is observed at higher levels of the cross-stratified units. This seems to point to sand avalanching as a prevailing process. However, several data disagree with this suggestion.

Deformational structures characteristic of sand avalanching (*cf.* McKee & *al.* 1971) are rarely encountered in the rocks of association *A*. The wedging out of cross-strata, which can be related to sand avalanching, has not been observed at the toes of the Tumlin dunes.

On the other hand, the following features are commonly encountered in association *A*: (1) Individual cross-laminae are very extensive, parallel and perpendicular to the direction of dip. (2) In *ac* sections the laminae are often straight at high levels of cross-stratified units and gradually bend downdip (in a concave-upward sense). (3) Individual laminae, as well as their bundles, gradually decrease in thickness, concordantly as a set thins; the thickness of individual laminae or of their bundles usually differs considerably in vertical sections. (4) Gradational contacts of the laminae are common, making individual laminae hardly discernible in many places. (5) The cross-laminae are usually more or less parallel.

All the above mentioned characteristics agree with the grainfall deposition on lee-slopes of modern dunes (Hunter 1977, pp. 375—377). It may thus be concluded that the process of grainfall deposition predominated on lee-slopes of the Tumlin dunes, while sand avalanching and tractional deposition played a secondary role there.

The present authors suggest that the sand avalanching was mainly of a sand-flow and not slumping type, since deformational structures of the latter type (*cf.* McKee & *al.* 1971) are extremely rare in the Tumlin Sandstone and are represented only by break-apart laminae, overthrusts and overturned folds. The features of individual laminae, especially their large lateral continuity, indicate that sand-flows were a result of a scarp recession rather than of a slump degeneration (*cf.* Hunter 1977, p. 377). Such sand-flows spread over large areas of the slope, and grains dropping down from a miniature upward-receding escarpment were accompanied with a wind-induced grainfall. The resultant accumulation of sand covered a large area of the slope with a relatively thin sheet and gradually faded out on its margins; hence the laminae which originated in this way did not noticeably differ from those formed by the wind-induced grainfall.

A tractional origin of part of the cross-laminae is suggested by the presence of ripples on some cross-stratification surfaces, as well as by the common occurrence of bundles of thin laminae of a similar thickness and with relatively distinct boundaries. Some of these bundles may represent a subcritically climbing translatent stratification (*sensu* Hunter 1977) while others, particularly those in lower parts of the lee-slopes, may be considered a planebed lamination.

The characteristics of the additional bounding surfaces that separate the inclined sets of cross-laminae indicate that in the Tumlin Sandstone most of these surfaces are erosional, and only few may be regarded as shear planes formed by sand avalanching. The additional bounding surfaces were mostly due to the action of air currents transversal or oblique to the direction of dune lee-slope inclination (*see* Walker & Harms 1972), as indicated by the truncation of the underlying cross--laminae seen in a plan view (*see* Pl. 6, Figs 1 & 2).

A similar spatial arrangement of individual inclined sets within the compound sets, as well as a small variability of the dip direction of steeply and moderately inclined cross-strata, both in individual exposures and over the whole area, suggests that association *A* is represented by deposits of transversal or barchanoid dunes with slightly sinuous crests. The dunes migrated as a result of the action of prevailing unidirectional winds.

The geometry of the very large-scale cross-stratified units of the Tumlin Sandstone, compared with that of different types of modern dunes from the White Sands dune field in New Mexico (*see* McKee 1966), resembles best the lower part of transversal dune sections. The differences consist mainly in a marked downdip bending of the Tumlin cross-strata, which may be explained by a secondary role played by sand avalanching in the origin of these strata.

The deposits of association *B* were laid down in interdune areas; this assumption is corroborated, first of all, by their spatial relations with the deposits of association *A*, as well as by their lithology and their sedimentary features.

Wind-blown deposits are prevailing in association *B*. Their aeolian origin is implied by a frequent occurrence of continuous transition into very large-scale cross-strata without any apparent change in the general character of their lamination, as well as by considerable lateral continuity of individual laminae or bundles of laminae, and by a horizontal, usually parallel lamination of these deposits. The details of such a lamination resemble features of stratification observed in the sand deposited by the wind in interdune areas or in a nearly flat apron at the base of modern dune slopes (*see* McKee 1966; Glennie 1970; McKee & Moiola 1975; Hunter 1977).

The deposits laid down in water or with the help of water usually occur in the form of subordinate intercalations or lenses within the wind-blown deposits of association *B*; they are not always observed in compound sets. Nevertheless, their presence indicates that in some interdune depressions sporadic short-lived water courses and infrequent shallow, ephemeral ponds were formed.

Vertical sequences observed in quarry walls usually reveal several subhorizontal compound sets, except for the cases discussed below. The bases of the compound sets are formed by subhorizontal main bounding surfaces which truncate the underlying deposits of dune lee-slopes. These surfaces are covered with prograding interdune deposits which pass upward into the deposits of dune lee-slopes. The latter are truncated by a successive main bounding surface. The origin of these sequences may be attributed to a fairly regular climbing of dunes one over another, migrating in nearly the same direction (*see* McKee & Moiola 1975, *cf. also* Shotton 1935). The climbing was possible when the amount of sand supplied to the dune field area exceeded that removed by the wind.

Each subhorizontal main bounding surface was formed due to a successive migration of the wind-erosion zone, extending over the windward slope of the dune and also probably over the adjoining part of the interdune area. In turn, the above mentioned surfaces were gradually covered with deposits accumulated in the remaining part of the interdune area, and later with those of the lee-slope of a successive dune. The deposits of the toes of dune windward-slopes are only sporadically preserved in a stratigraphic record (see Pl. 1).

The presence of giant scoop-like surfaces indicates that the process of accumulation of the Tumlin Sandstone was more complex than it is suggested above. Each giant scoop-like surface bevels two or more subhorizontal componud sets and serves as a base of deposition of a new compound set. These surfaces are similar in their unidirectional orientation and shape to the additional bounding surfaces separating the inclined sets. This points to an analogous origin of both types of surfaces, the only difference lying in the scale. The present authors consider the scoop-like parts of the main bounding surfaces to be exclusively a result of the aeolian erosion, but a detailed interpretation of the processes involved is difficult. It is noteworthy that similar surfaces also occur in the Permian dune deposits of the Flechtiger Bausandstein (*see* Ellenberg & *al.* 1976, Fig. 2). It is not unlikely that further examples of such surfaces will be found in other fossil or modern dune deposits.

The present data indicate that during the development of the Tumlin dune-field there existed remarkable differences between the level of interdune areas separating the regularly climbing dunes and that of isolated, lower situated interdune depressions. The latter depressions were cut into deposits of some older dune generations. A similar situation, *i.e.* the presence of two levels of the interdune areas, was observed by the first of the present authors at the modern dune field Khongoreen Els in the Gobi Desert in southern Mongolia.

The ground-water level in the Tumlin field probably did not reach the bottom even of the lowermost depressions. Rare but heavy rainfalls gave rise to ephemeral water flows at the bottom of some interdune areas, as well as to the formation of ephemeral, shallow, and quickly evaporating ponds. The deposits laid down by these waters were rapidly buried by wind-blown sands.

The area of occurrence of the Tumlin Sandstone is situated within the Danish-Polish Trough, along the axis of the maximum thickness of Mesozoic rocks (*cf.* Kutek & Głazek 1972). It is not unlikely that the subsidence accompanied with an arid or semiarid climate favoured the development of a midcontinental, generally dry, local and possibly closed basin. The central part of the basin was at first occupied by a playa, the deposits of which underlie the Tumlin Sandstone, succeded by a dune field.

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REFERENCES

BAGNOLD R. A. 1941. The physics of blown sand and desert dunes. 265 pp. *Methuen,* London.

BIGARELLA J. J. 1972. Eolian environments: their characteristics, recognition, and importance. *In:* J. H. RIGBY & W. K. HAMBLIN *(Eds),* Recognition of ancient sedimentary environments. *Soc. Econ. Pal. Min., Spec. Publ.,* **16,** 12—62. Tulsa.

BROOKFIELD M. E. 1977. The origin of bounding surfaces in ancient aeolian sandstones. *Sedimentology,* **24,** 393—332. Oxford.

CAMPBELL C. V. 1967. Lamina, laminaset, bed and bedset. *Sedimentology,* **8,** 7—26. Amsterdam.

CARTER R. M. 1975. Mass-emplaced sand-fingers at Mararoa construction site, southern New Zealand. *Sedimentology,* **22,** 275—288. Oxford.

CURRAY J. C. 1956. The analysis of two-dimensional orientation data. *J. Geol.,* **64,** 117—131. Chicago.

DEMBOWSKA J. 1957. Trias. *Biul. Inst. Geol.,* **124,** 82—93. Warszawa.

ELLENBERG J., FALK F., GRUMBT E., LÜTZNER H. & LUDWIG A. O., 1976. Sedimentation des höheren Unterperms der Flechtingen Scholle. *Zt. Geol. Wiss.*, **5**, 705—737. Berlin.

FLEMMING B. W. 1977. Langebaan lagoon: a mixed carbonate-siliciclastic tidal environment in semiarid climate. *Sedim. Geol.*, **18**, 61—95. Amsterdam.

GĄGOL J. 1976. Kamieniołom Tumlin-Gród — piaskowce tumlińskie. In: *Przewodnik 48 Zjazdu PTG*, 232—235. *Wyd. Geol.*, Warszawa.

— & KARPINIEC J. 1974. Warstwowanie i struktury sedymentacyjne w piaskowcach tumlińskich. *Kwart. Geol.*, **18**, 448—449. Warszawa.

GLENNIE K. W. 1970. Desert sedimentary environments. *Developments in sedimentology*, **14**, 222 pp. *Elsevier*, Amsterdam.

— 1972. Permian Rotliegendes of northwest Europe interpreted in light of modern desert sedimentation studies. *Amer. Ass. Petrol. Geol. Bull.*, **56**, 1048—1071. Tulsa.

GODWARD N. E. (Ed.), Rock color Chart. *Geol. Soc. Amer.*, New York.

GRADZIŃSKI R. & JERZYKIEWICZ T. 1974. Dinosaur- and mammal-bearing aeolian and associated deposits of the Upper Cretaceous in the Gobi Desert (Mongolia). *Sedim. Geol.*, **12**, 249—278. Amsterdam.

HARSHBAGGER J. W., REPENNING C. A. & IRVING J. H. 1957. Stratigraphy of the uppermost Triassic and Jurassic rocks of the Navajo Country. *U. S. Geol. Surv. Prof. Pap.*, **291**, 1—74. Washington.

HÄNTZSCHEL W. & REINECK H.-E. 1968. Faziesuntersuchungen im Hettangium von Helmstedt (Niedersachsen). *Mitt. Geol. Staatsinst.*, **37**, 5—39. Hamburg.

HORNE R. R. 1971. Eolian cross-stratification in the Devonian of the Dingle Peninsula, County Kerry, Ireland. *Geol. Mag.*, **108** (2), 151—158. Oxford.

HUNTER R. E. 1977. Basic types of stratification in small eolian dunes. *Sedimentology*, **24**, 361—387. Oxford.

KRINSLEY D. H. & DOORNKAMP J. C. 1973. Atlas of quartz and sand surface textures. 91pp. *Cambridge University Press*, Cambridge.

KRUMBEIN W. C. & SLOSS L. L. 1963. Stratigraphy and sedimentation *(2nd ed.)*, 660 pp. *Freeman*, San Francisco.

KUTEK J. & GŁAZEK J. 1972. The Holy Cross area, Central Poland in the Alpine cycle. *Acta Geol. Pol.*, **22** (4), 603—653. Warszawa.

LAND L. S. 1964. Eolian cross-bedding in the beach dune environment, Sapelo Island, Georgia. *J. Sediment. Petrol.*, **34**, 389—394. Tulsa.

MARGOLIS S. & KRINSLEY D. 1971. Submicroscopic frosting on eolian and subaqueous quartz grains. *Bull. Geol. Soc. Am.*, **82**, 3395—3406. Boulder.

McKEE E. D. 1966. Structures of dunes at White Sands National Monument, New Mexico (and comparison with structures of dunes from other selected areas). *Sedimentology*, **7**, 1—69. Amsterdam.

— & DOUGLASS J. R. 1971. Growth and movement of dunes at White Sands National Monument, New Mexico, *U.S. Geol. Prof. Paper* **750-D**, 108—114 New York.

—, — & RITTENHOUSE S. 1971. Deformation of lee-side laminae in eolian dunes. *Bull. Geol. Soc. Am.*, **82**, 359—378. Boulder.

— & MOIOLA R. J. 1975. Geometry and growth of the White Sands dune field, New Mexico. *Jour. Research U.S. Geol. Surv.*, **3**, 59—66.

MINTER W. E. L. 1970. Origin of mud polygons that are concaved downward. *J. Sediment. Petrol.*, **40**, 755—756. Tulsa.

NORRIS R. M. & NORRIS K. S. 1961. Algodones dunes of southeastern California. *Bull. Geol. Soc. Amer.*, **72**, 605—620. New York.

PAWLICA W. 1920. Ilaste rudy żelazne Starachowic. *Spraw. Państw. Inst. Geol.*, **1** (1), 1—52. Warszawa.

PEACOCK J. O. 1966. Contorted beds in the Permo-Triassic aeolian sandstones of Morayshire. *Bull. Geol. Surv. Gr. Brit.*, **24**, 157—162. London.

PICARD M. D. & HIGH L. R., Jr. 1973. Sedimentary structures of ephemeral streams. *Developments in Sedimentology*, **17**, 223 pp. Elsevier. Amsterdam.

POOLE F. G. 1962. Wind directions in Late Paleozoic to Middle Mesozoic time on the Colorado Plateau. *U. S. Geol. Survey Prof. Paper*, **450-D**, 147—151. Washington.

RAAF J. F. M. de, BOERSMA J. R. & GELDER A. van, 1977. Wave generated structures and sequences from a shallow marine succesion, Lower Carboniferous, County Cork, Ireland. *Sedimentology*, **24**, 451—483. Oxford.

REINECK H.-E. 1955. Haftrippeln und Haftwarzen, Ablagerungsformen von Flugsand. *Senkenberg. Lethaea*, **36**, 347—357. Frankfurt a.M.

— 1961. Sedimentbewegungen an klein Rippeln im Watt. *Senkenberg. Lethaea*, **42**, 51—61. Frankfurt am M.

— & SINGH J. B. 1973. Depositional sedimentary environments. 439 pp. *Springer*, Berlin.

RONIEWICZ P. 1965. Contribution on mud crack formation. *Rocz. Pol. Tow. Geol.* **35** (2), 211—220. Kraków.

SAMSONOWICZ J. 1929. Cechsztyn, trias i lias na północnym zboczu Łysogór. *Spraw. Państw. Inst. Geol.*, **5** (1), 1—250. Warszawa.

SANDERSON I. D. 1974. Sedimentary structures and their environmental significance in the Navajo Sandstone, San Rafael Swell, Utah. *Bringham Young Univ. Geol. Studies*, **21**, 215—246.

SENKOWICZOWA H. 1970. Trias. *In*: Stratygrafia mezozoiku obrzeżenia Gór Świętokrzyskich. *Prace Inst. Geol.*, **56**, 7—48. Warszawa.

— 1973. Góry Świętokrzyskie — piaskowiec pstry dolny i środkowy. *In: Budowa geologiczna Polski*, **I** (2), 56—64. Wyd. Geol. Warszawa.

— & ŚLĄCZKA A. 1962. Pstry piaskowiec na północnym obrzeżeniu Gór Świętokrzyskich. *Rocz. Pol. Tow. Geol.*, **32** (3), 313—337. Kraków.

SHARP R. P. 1963. Wind ripples. *J. Geol.*, **71**, 617—636. Chicago.

SHOTTON F. W. 1937. The Lower Bunter Sandstones of North Worcestershire and East Shropshire. *Geol. Mag.*, **74** (882), 534—553. London.

SHROCK R. R. 1948. Sequence in layered rocks. 507pp. *McGraw-Hill*. New York

STEIDTMANN J. R. 1974. Evidence for eolian origin of cross-stratification in sandstone of Casper Formation, southermost Laramie Basin, Wyoming *Geol. Soc. Amer. Bull.*, **85**, 1835—1842. Boulder.

ŚLĄCZKA A. & RONIEWICZ P. 1971. Kamieniołom w Ciosowej. *In: Przewodnik 43 Zjazdu PTG*, 55—56. Wyd. Geol. Warszawa.

TANNER W. F. 1964. Eolian ripple marks in sandstone. *J. Sedim. Petrol.*, **34** (2), 432—433. Tulsa.

THOMPSON D. B. 1969. Dome shaped eolian dunes in the Frodsham Member of the so-called "Keuper" Sandstone Formation (Scythian — ?Anisian; Triassic) at Frodsham, Cheshire (England). *Sediment. Geology*, **3**, 263—289. Amsterdam.

WALKER T. R. & HARMS J. C. 1972. Eolian origin of Flagstone Beds, Lyons Sandstone (Permian), type area, Boulder County, Colorado. *Mountain Geologist*, **9**, 279—288.

WRIGHT H. E., Jr. 1956. Origin of the Chuska sandstone, Arizona and New Mexico: A structural and petrographic study of a Tertiary eolian sediment *Bull. Geol. Soc. Amer.*, **67**, 413—434. New York.

R. GRADZIŃSKI, J. GĄGOL i A. ŚLĄCZKA

PIASKOWCE Z TUMLINA — OSADY WYDM EOLICZNYCH I OBNIŻEŃ MIĘDZYWYDMOWYCH W PSTRYM PIASKOWCU PÓŁNOCNO-ZACHODNIEGO OBRZEŻENIA GÓR ŚWIĘTOKRZYSKICH

(Streszczenie)

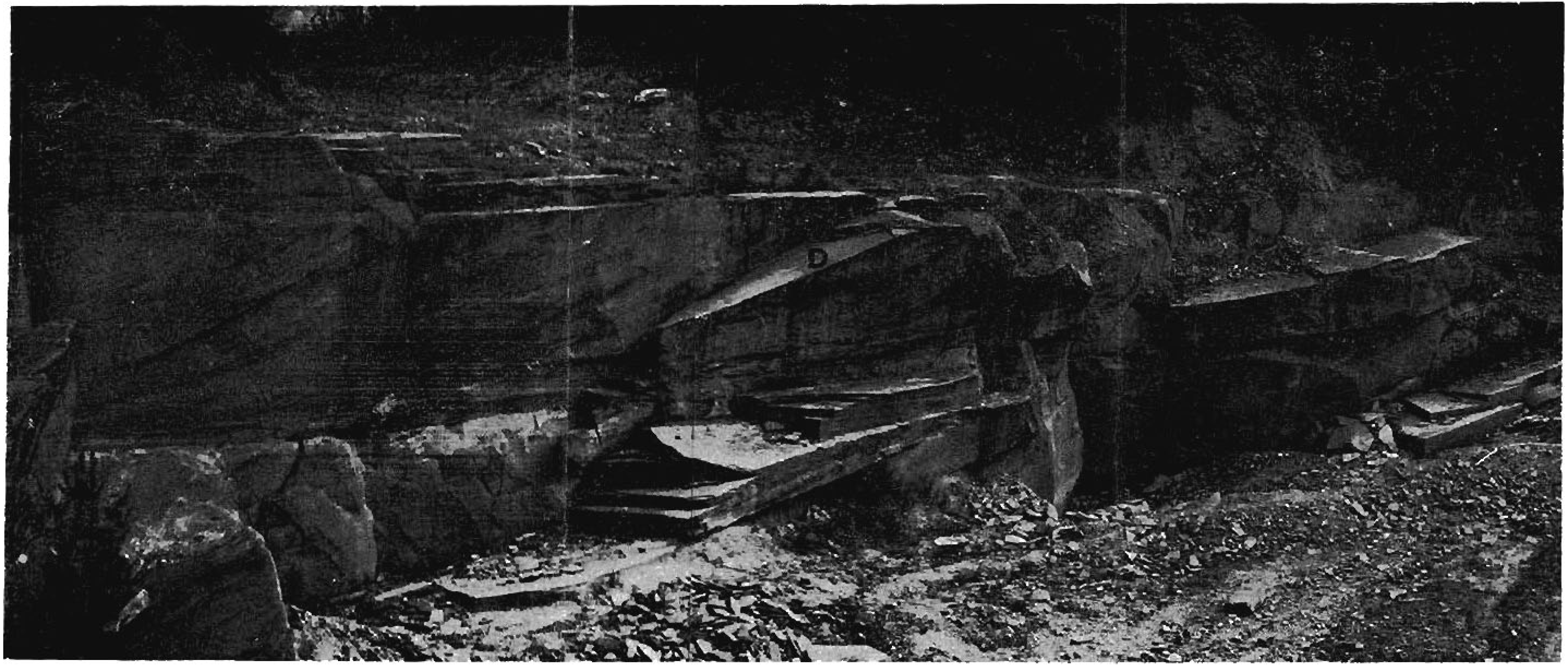
Przedmiotem pracy jest analiza sedymentologiczna piaskowców z Tumlina, stanowiących część nieformalnej jednostki litostratygraficznej znanej jako warstwy z Tumlina. Omawiane piaskowce występują na stosunkowo niewielkim obszarze w północno-zachodnim obrzeżeniu Gór Świętokrzyskich (fig. 1). Analiza przeprowadzona została przede wszystkim na podstawie licznych struktur sedymentacyjnych (*patrz* fig. 4—9, tab. 2—3 oraz pl. 1—21), a w mniejszym stopniu w oparciu o cechy teksturalne (*patrz* fig. 2—3, tab. 1 oraz pl. 22—24).

Dominujące w piaskowcach z Tumlina osady o wielkoskalowym warstwowaniu przekątnym, określone w pracy jako asocjacja *A*, zawierają zespół struktur sedymentacyjnych charakterystyczny dla osadów zawietrznych stoków wydm. Warstwy przekątne z reguły spłaszczają się w dół upadu sedymentacyjnego, a często poupadowo przechodzą w warstwy połogie, wchodzące w skład asocjacji *B*, interpretowanej jako osady obniżeń międzywydmowych. Większość osadów tej asocjacji jest również pochodzenia eolicznego. Podrzędnie tylko występują wśród nich cienkie wkładki osadów powstałych w wyniku krótkotrwałych, rzadkich ulew; te osady deponowane były zarówno w płytkich, efemerycznych zbiornikach wodnych (warstewki mułowców z śladami wysychania) jak i przez wodę płynącą (piaskowce bezstrukturowe wypełniające lokalne kanały erozyjne).

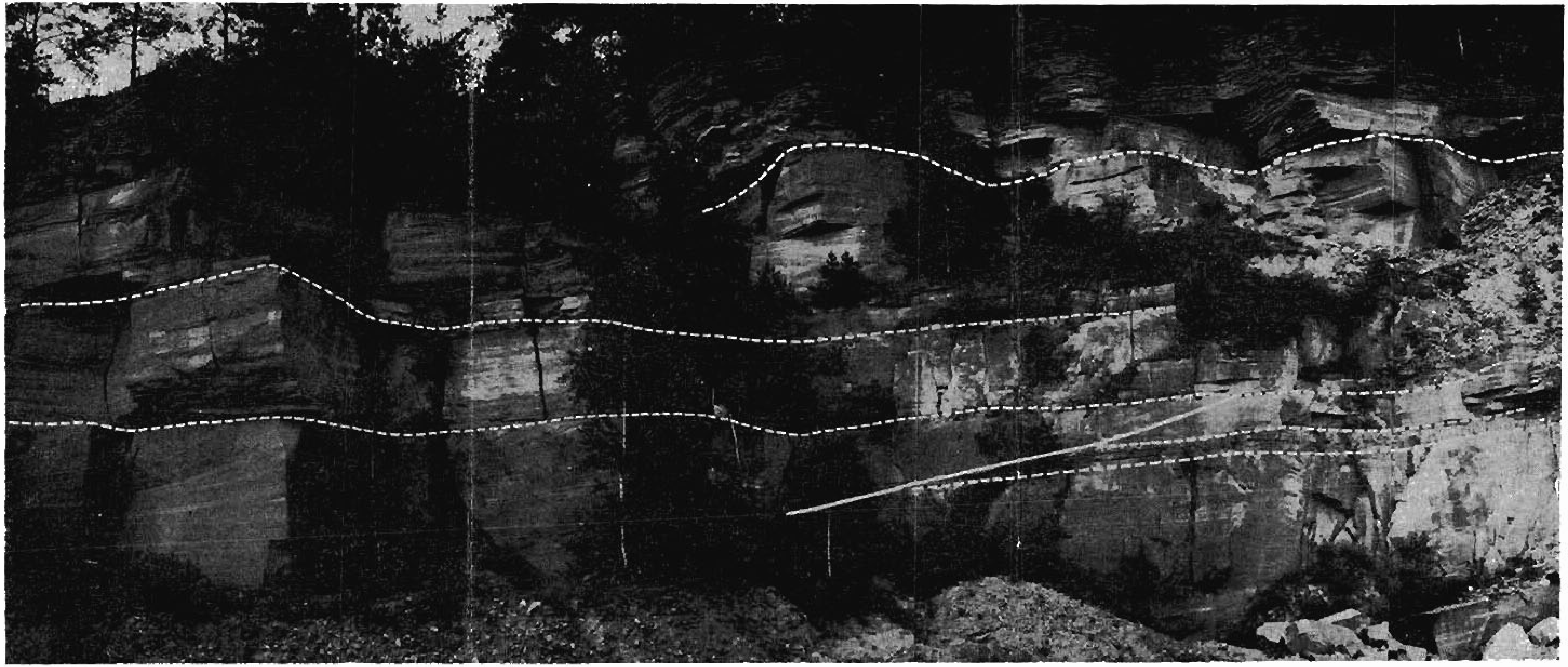
Piaskowce z Tumlina są osadami pola wydm transwersalnych (poprzecznych prostych), które migrowały pod wpływem wiatrów wiejących ogólnie ku północy. Pole wydm tumlińskich zajmowało środkową część lądowego basenu, leżącego w osi strefy maksymalnej subsydencji bruzdy duńsko-polskiej. Z danych wiertniczych wynika, że piaskowce z Tumlina podścielone są osadami obszaru o typie playa.

Upper wall in quarry Tumlin-Gród (*cf.* Text-fig. 6). Very large-scale cross-stratified sandstones of association *A* in lower part of wall are truncated by main bounding surface (**M**), indicated with hand by the standing man. Sandstones of association *B* above this surface (*M*) have several generations of erosional channels filled with structureless sandstone; sandstones of association *B* are inclined to S (left). Probable deposits of dune stoss-side are in right-center; their preservation is exceptional. At right the deposits are bevelled by a giant scoop-like surface

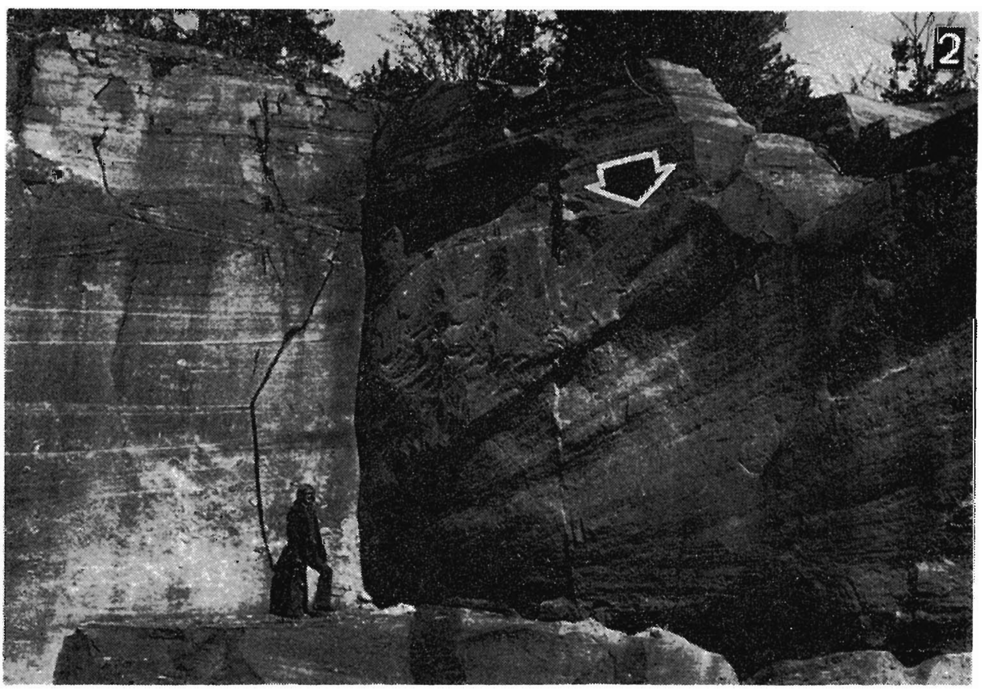
Northern part of western wall in quarry Tumlin-Gród (cf. Text-fig. 5), December 1974. Steeply inclined fragment of giant scoop-like surface (**K**) indicated by solid arrow; blank arrow shows younger main bounding surface (**M**). At upper left deposits of association *A* transitional downdip into those of association *B*. Lateral transition from laminated sandstones into layer devoid of discernible lamination is visible at right, above surface (*M*) and left of the blank arrow



Eastern wall in quarry Tumlin-Gród (*cf.* Text-fig. 4), May 1975. Three compound sets of strata separated by almost horizontal main bounding surfaces. Lower compound set shows only deposits of association *A*, central one is composed in lower part of deposits of association *B*, in upper part of deposits of association *A*. Upper compound set shows only deposits of association *B* (at left). Small fragment of giant scoop-like surface, inclined to N is shown in upper left corner. Arrow points to location of water-level terraces and footprints (*see* Pl. 19). Aeolian ripples are present of triangular, inclined surface visible in center (*D*); below it, a fragment of wall (*E*) shown in Pl. 13, Fig. 2

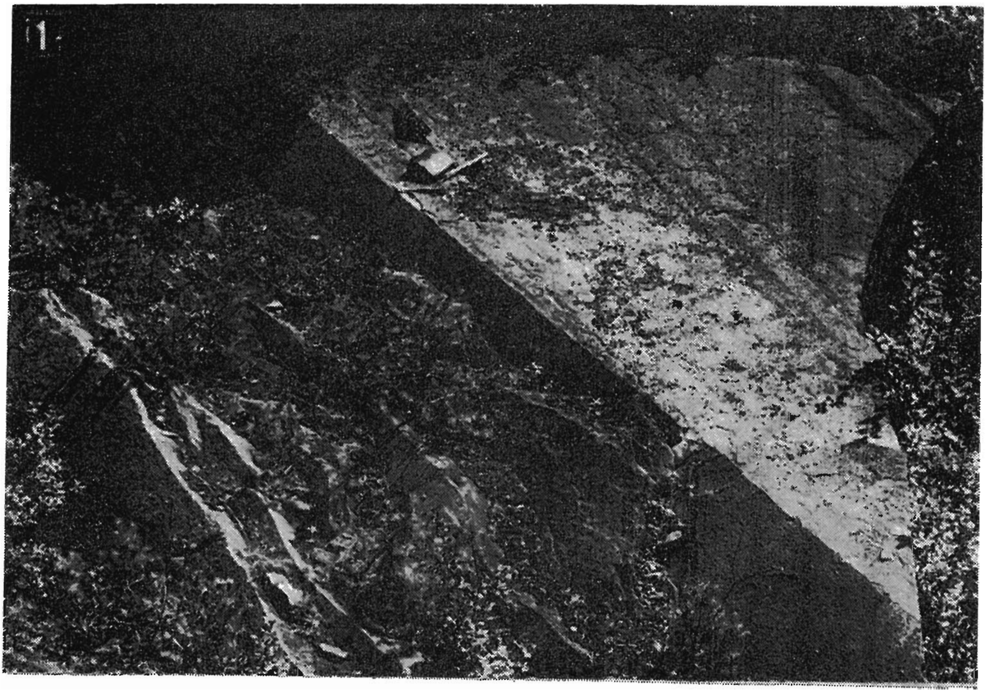


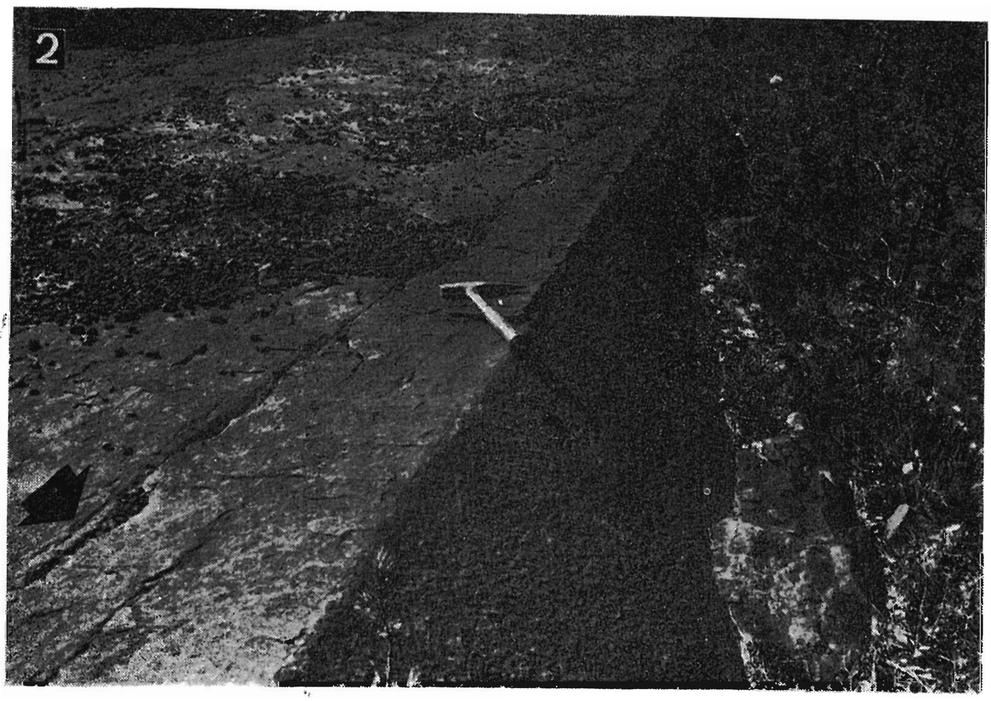
Western part of northern wall in quarry Ciosowa. Wall extends nearly perpendicular to tectonic dip and to cross-laminae inclination. Note that thickness of compound sets of strata is generally less than in quarry Tumlin-Gród, and intercalations of water-laid deposits (marked with dashed lines) are exceptionally numerous. Solid line shows fragment of giant scoop-like surface bevelling two intercalations of water-laid deposits. Wall height c 20 m



1 — Extensive, flat surfaces of cross-strata truncated by subhorizontal main bounding surface (a man stands on it). This surface is overlain by deposits of association *B* with water-laid intercalation. Arrow shows mud-cracked surface (*see* Pl. 16, Fig. 1). Ciosowa quarry

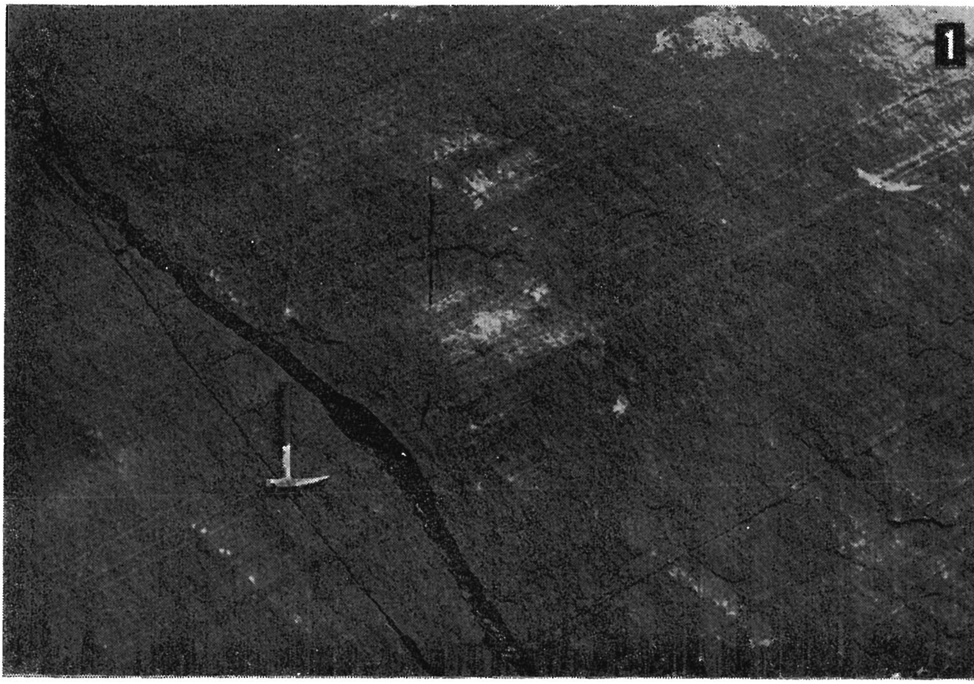
2 — Compound set of strata in corner formed by eastern (right) and northern walls of quarry Tumlin-Gród (*cf.* Text-fig. 4). Man stands on lower main bounding surface, upper bounding surface indicated by arrow

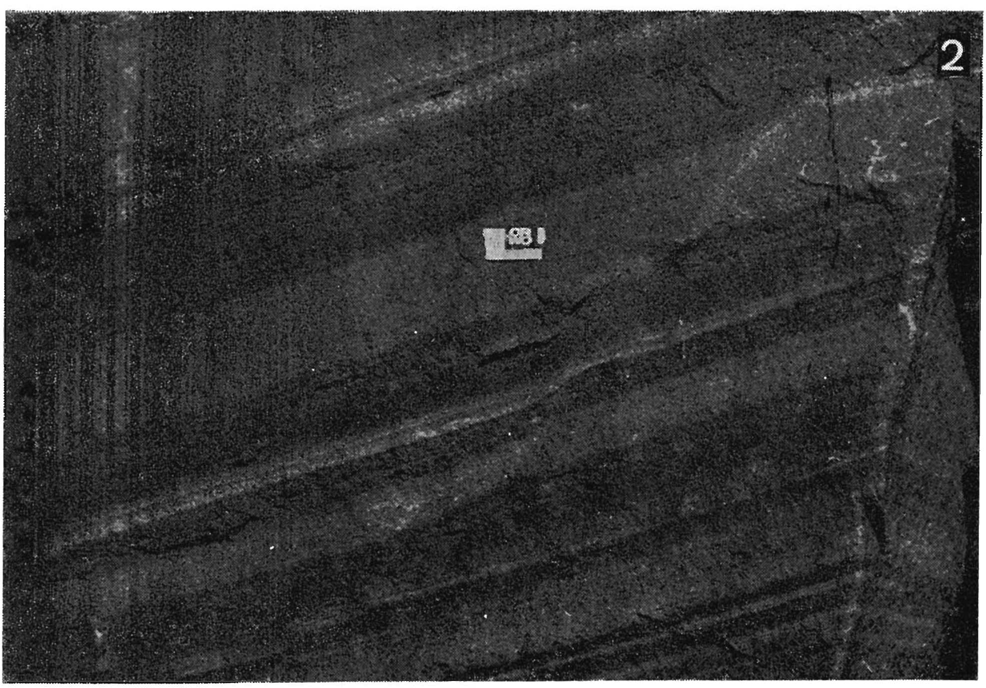




1 — Subhorizontal main bounding surface M (upper left) and inclined additional bounding surface (left of hammer). Another, older additional bounding surface is indicated by arrow. Rectilinear traces of truncated cross-strata of association *B* are visible on main bounding surface. Note shape of additional bounding surfaces. Quarry Tumlin-Gród; oblique downward-eastward view from top of upper wall (cf. Text-fig. 6 and Pl. 1)

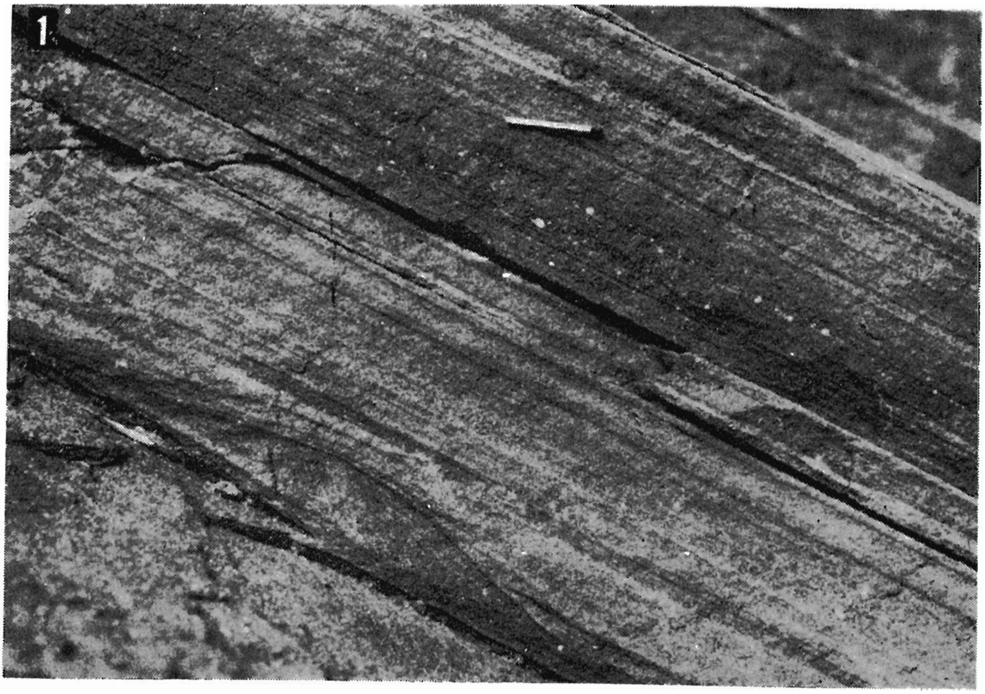
2 — Detail of exposure shown in Fig. 1, viewed westward. Main bounding surface M at left; arrow indicates older additional bounding surface. Right of hammer, exposed inclined, flat additional bounding surface

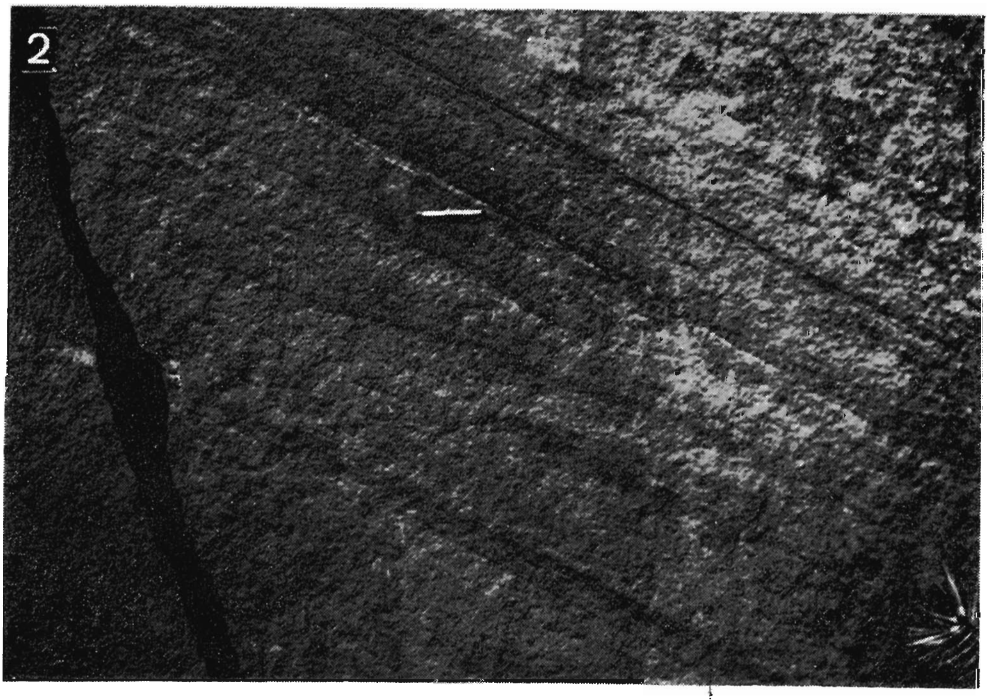




1 — Lamination in association *A* (section *ac*); note continuity of individual cross--laminae. Ciosowa quarry

2 — Cross-laminae in association *A*; note variable thickness and distinctness of individual laminae. Ciosowa quarry. Width of paper 5 cm





1 — Lamination in association *A* (section *ac*). Ciosowa quarry, detail of cross-strata shown on Pl. 5, Fig. 1. Note variations in grain-size. Gentle fold is visible at lower left. Match for scale

2 — Overthrusted cross-laminae (detail of upper wall in quarry Tumlin-Gród marked **L** on Text-fig. 6). Match for scale

Deformations on surfaces of cross-strata

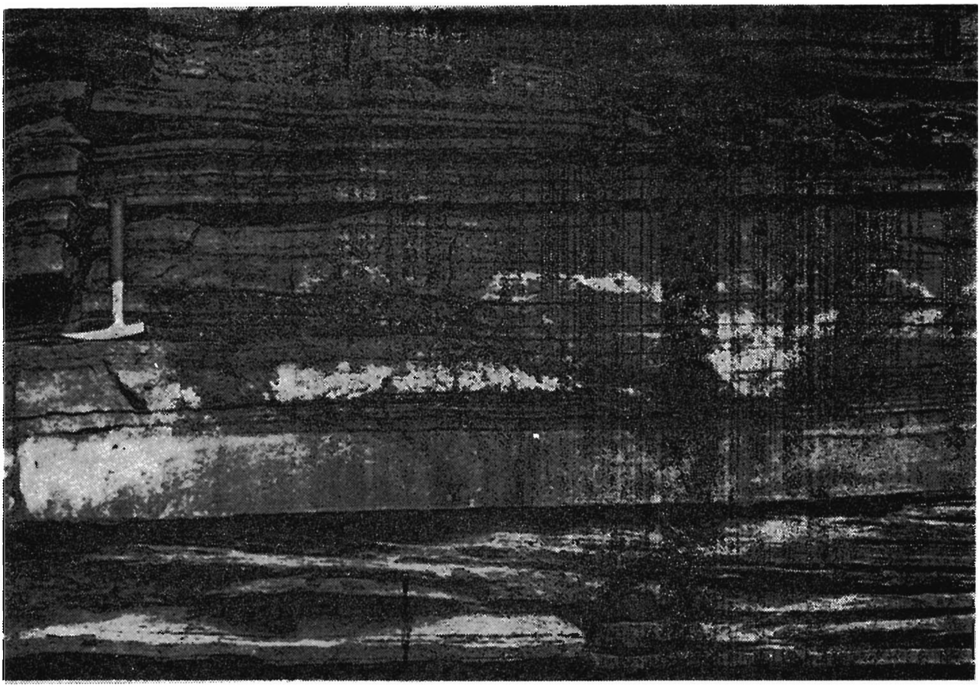
1 — Slightly undulated surface with miniature steps. Quarry Tumlin-Gród. Match for scale

2 — Miniature steps oriented updip. Quarry Tumlin-Gród. Match for scale

Aeolian ripples on surfaces of cross-strata; Sosnowica quarry

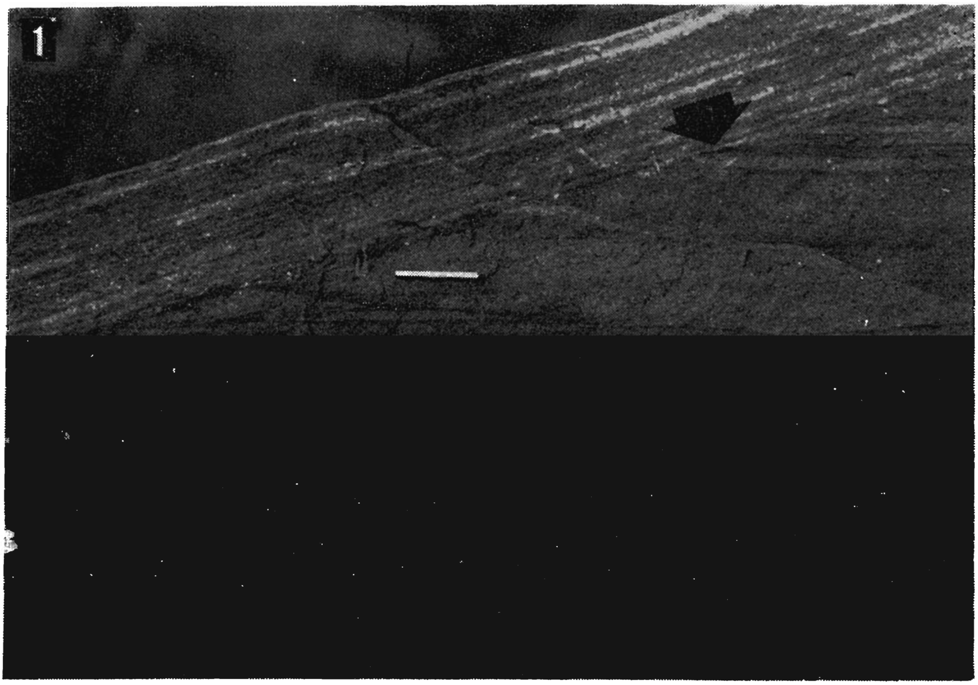
1 — Original dip of surface — 15°. Scale given by pencil 18 cm long set parallel to strike

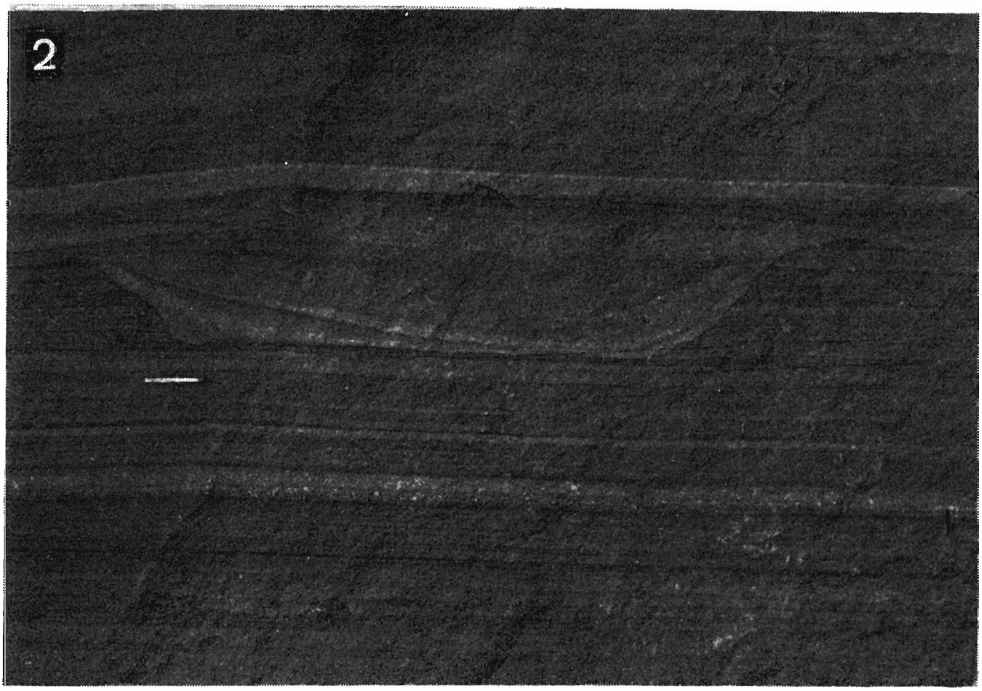
2 — Fragments of three surfaces of cross-strata; original dip — 12°. Scale given by pencil, 17 cm long, set parallel to strike



1 — Stratification in deposits of association *B*. In lower part deposits of association *A* (seen approximately in *bc* section) truncated by main bounding surface. Ciosowa quarry

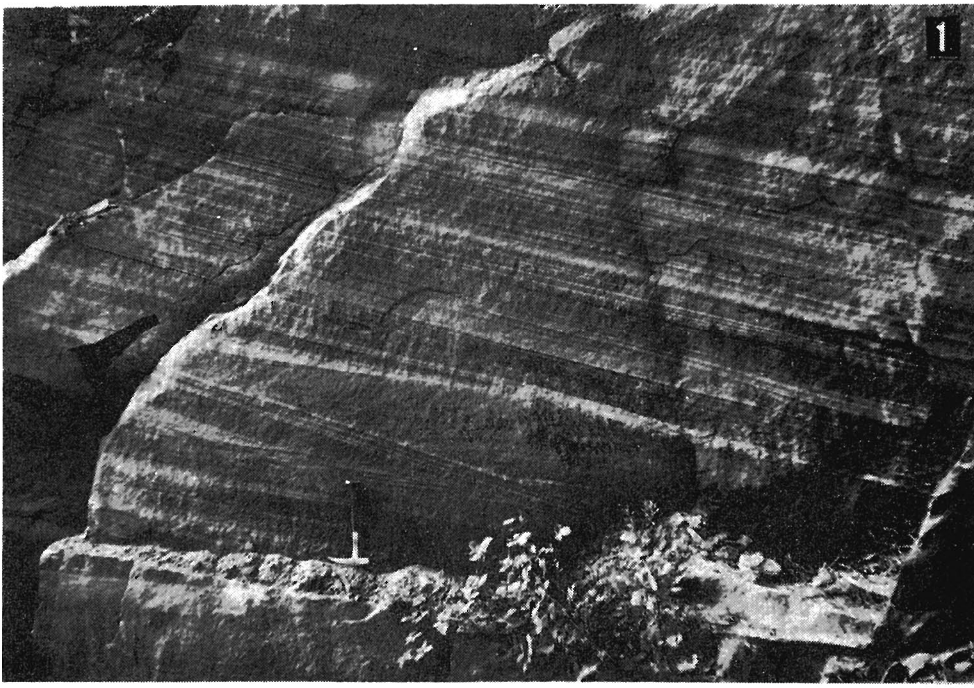
2 — Lens of coarser grains in deposits of association *B*. Ciosowa quarry





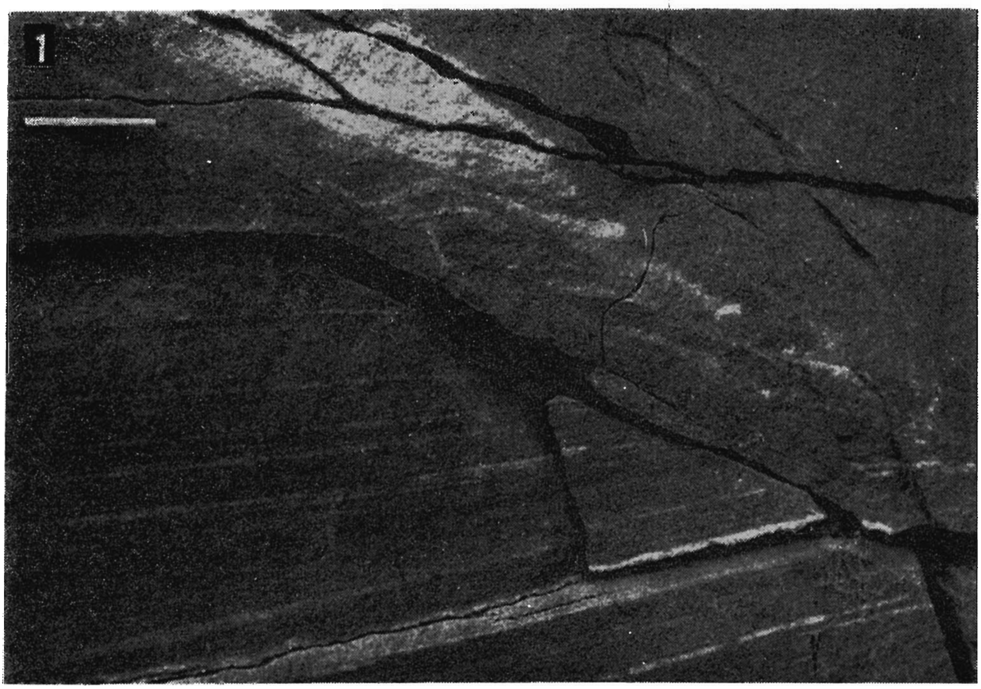
1 — Laminated sandstones of association *B*, bevelled by giant scoop-like surface (indicated by arrow). This surface is overlain by bundle of cross-laminae parallel to it. Quarry Tumlin-Gród. Match for scale

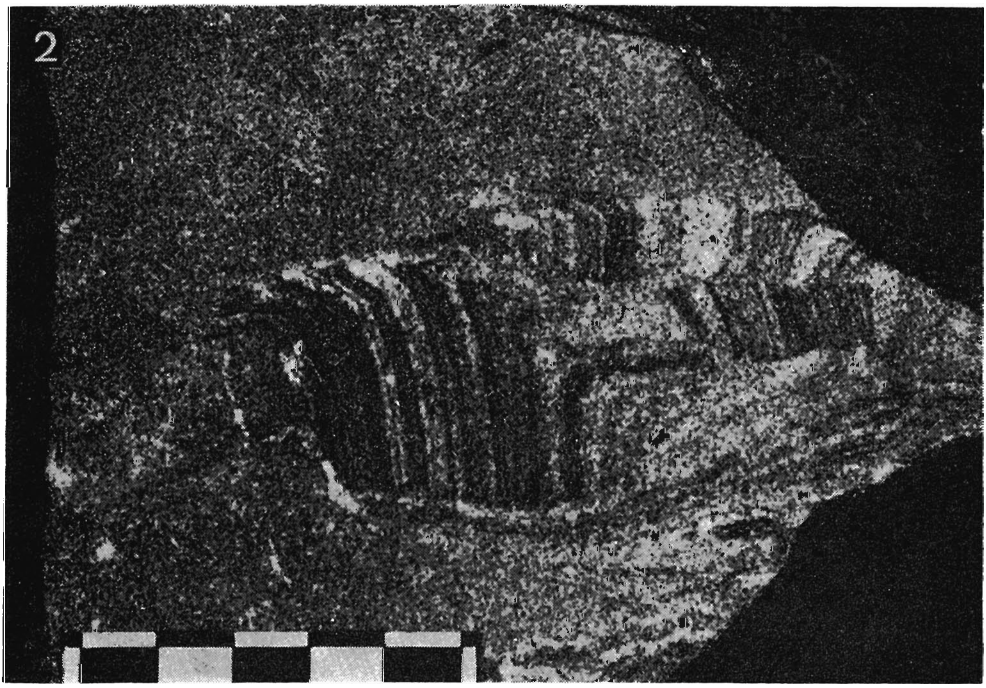
2 — Cross-section of avalanche scour in laminated sandstones of association *A*; section is perpendicular to dip of cross-laminae. Ciosowa quarry. Match for scale



1 — Gently inclined deposits of association *B* in section oblique to dip. In lower part intrasets consisting of laminae with slightly differing directions of dip. Ciosowa quarry

2 — Interfingering deposits of association *A* (cross-stratified intrasets) with deposits of association *B*. Selected strata chalked for clarity. Detail *D* of eastern wall in quarry Tumlin-Gród (*see* Text-fig. 4). Pencil 15 cm long for scale





1 — Bending of laminae at bank of erosional channel filled with structureless sandstone. Detail **H** of upper wall in quarry Tumlin-Gród (*see* Text-fig. 6 and Pl. 1). Match for scale

2 — Rotated block of laminated sediment in structureless sandstone filling erosional channel. Quarry Tumlin-Gród. Scale in centimetres

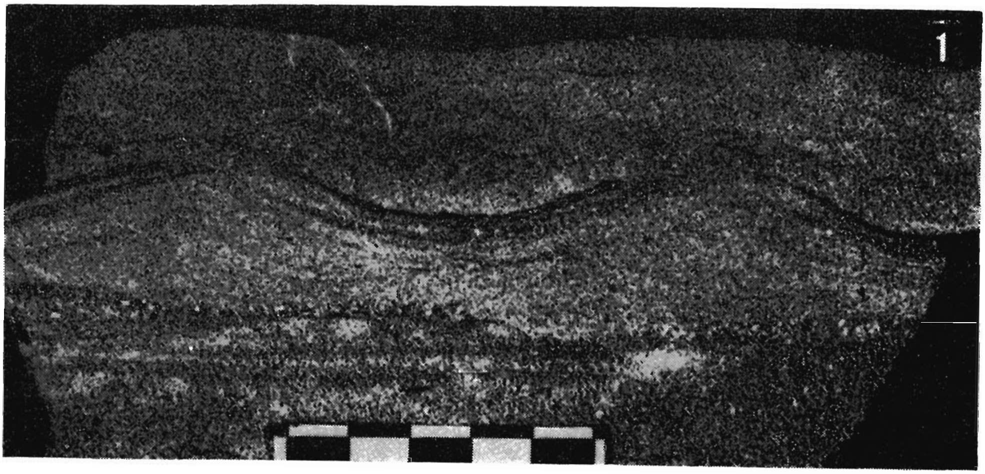
Surface relief of lenses of structureless sandstones

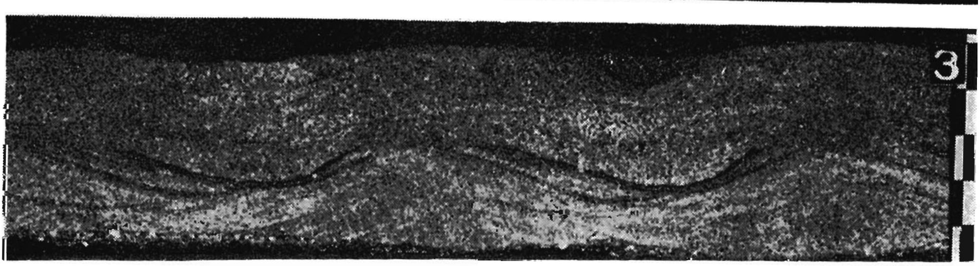
1 — Irregular bulbous relief; at lower right deformations of laminated sediment near structureless sandstone. Quarry Ciosowa. Box 5 cm long

2 — Sublinear relief with distributary rill pattern. Quarry Ciosowa. Pencil 15 cm long

1 — Mud cracks formed in very thin mud layer and preserved as prints on surface of underlying sandstone. Ciosowa quarry (for location, see Pl. 5, Fig. 1)

2 — Wave ripples in deposits of association *B*. Ciosowa quarry



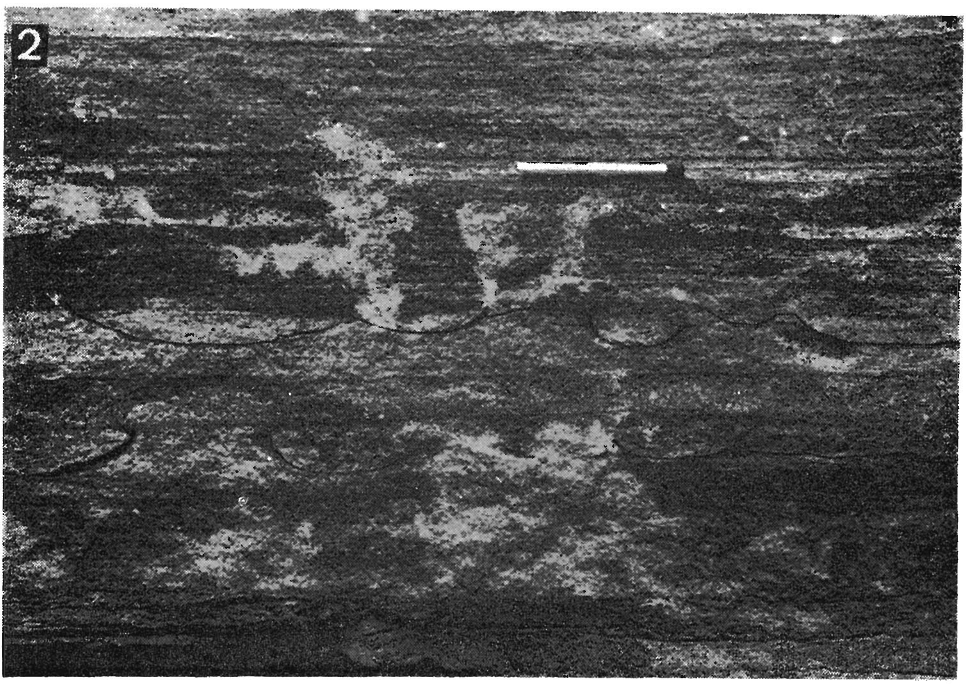


Cross-sections of wave ripples; deposits of association B, Ciosowa quarry. Scale in centimetres

1 — Chevron structures; mud lenses preserved in troughs

2 — Asymmetrical ripples; cross-laminae inclined in direction opposite to steeper sides of ripples. Note horizontal stratification below and above the ripples

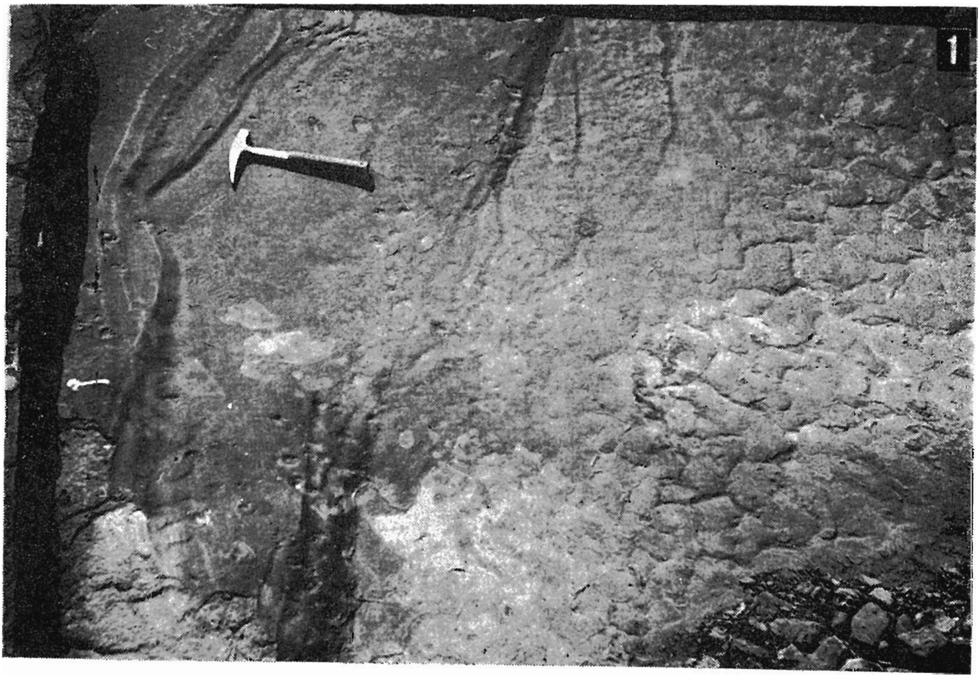
3 — Wave ripples of complex internal structure. Note marks of erosion in crests and mud lenses in troughs



Curled mud flakes

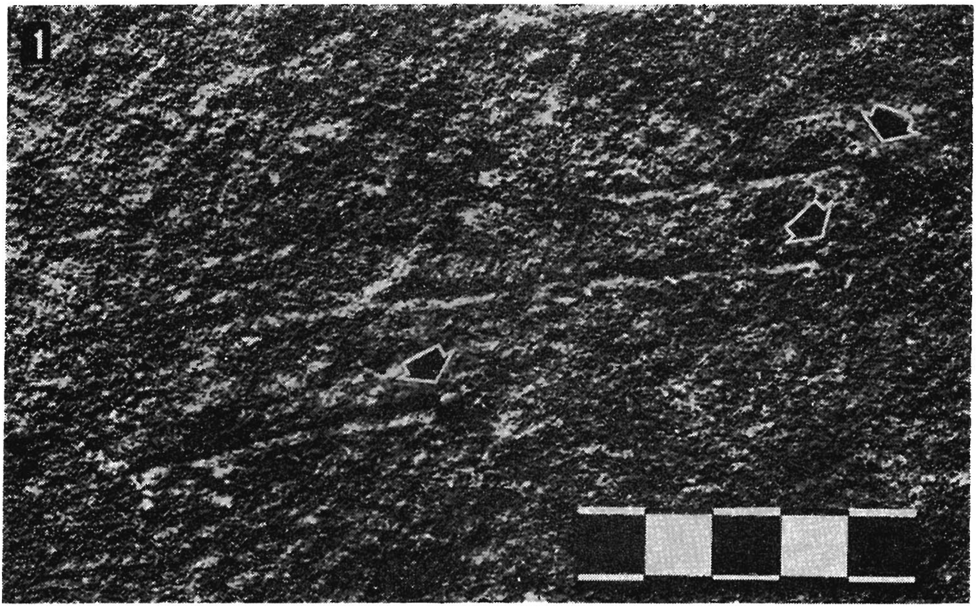
1 — **Bottom view** of layer filled with curled mud flakes. Sosnowica quarry. Box 5 cm long

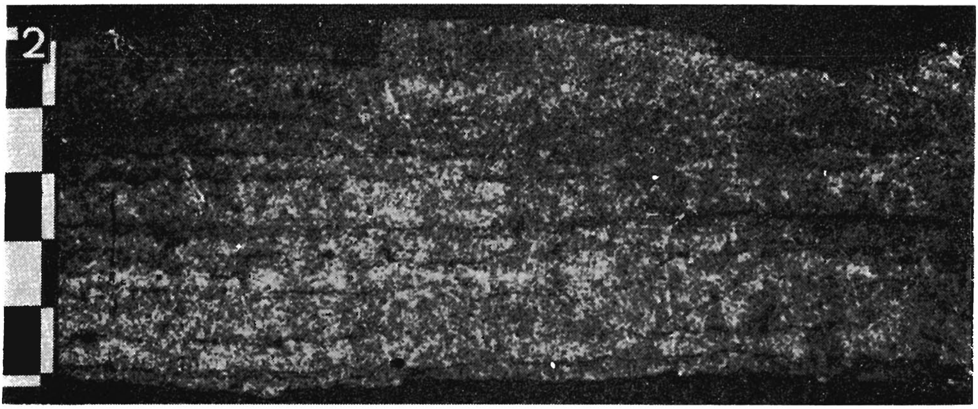
2 — Laminated sandstones of association *B* with visible sections of curled mud flakes. Note mode of burial of flakes and their minimal thickness. Sosnowica quarry. Match for scale

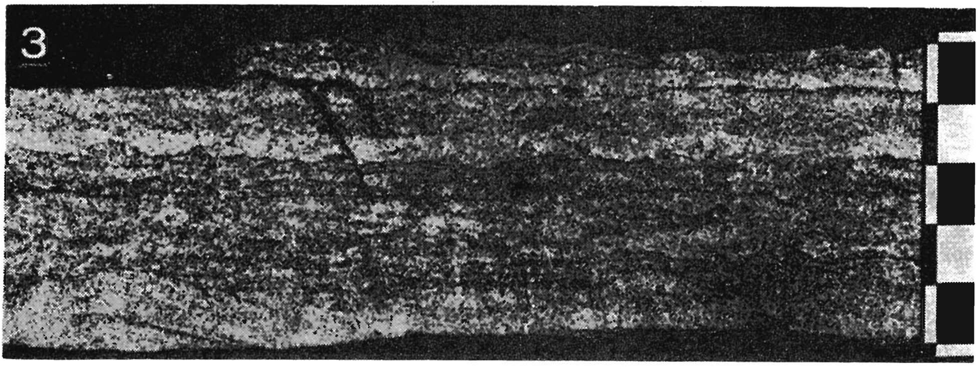


1 — Margin of ephemeral pond exposed in eastern wall of quarry Tumlin-Gród (*see* Text-fig. 4 and Pl. 3). At right, surface covered with mud cracks; at left and center, two sets of water-level terraces; footprints are on and between water-level terraces

2 — Footprints on higher set of water-level terrace. Wrinkle marks are below coin. Detail of Fig. 1; diameter of coin 24 mm





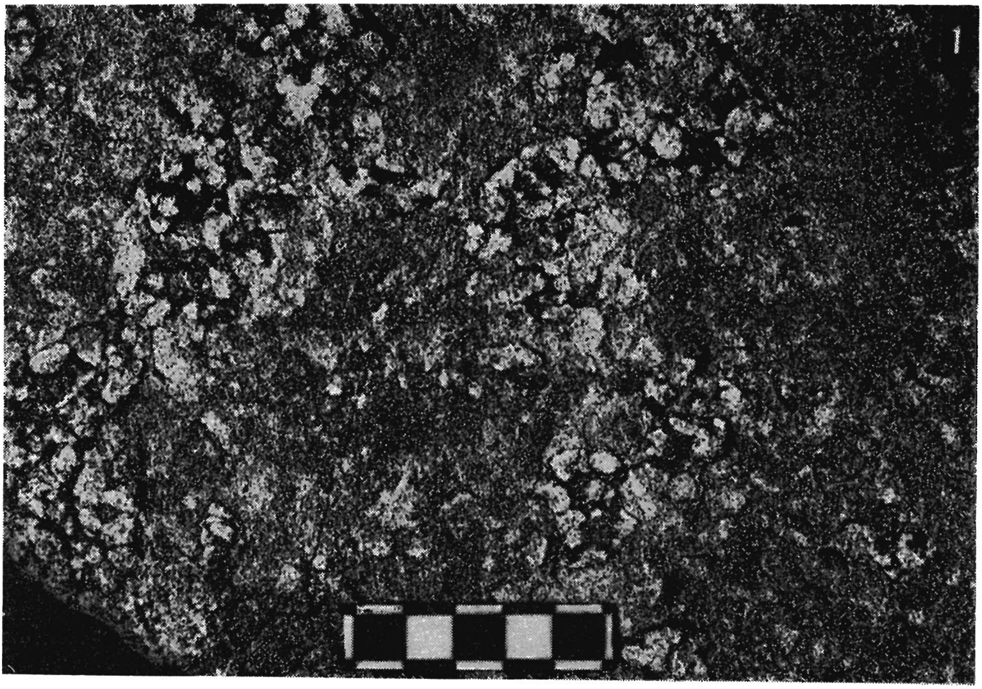


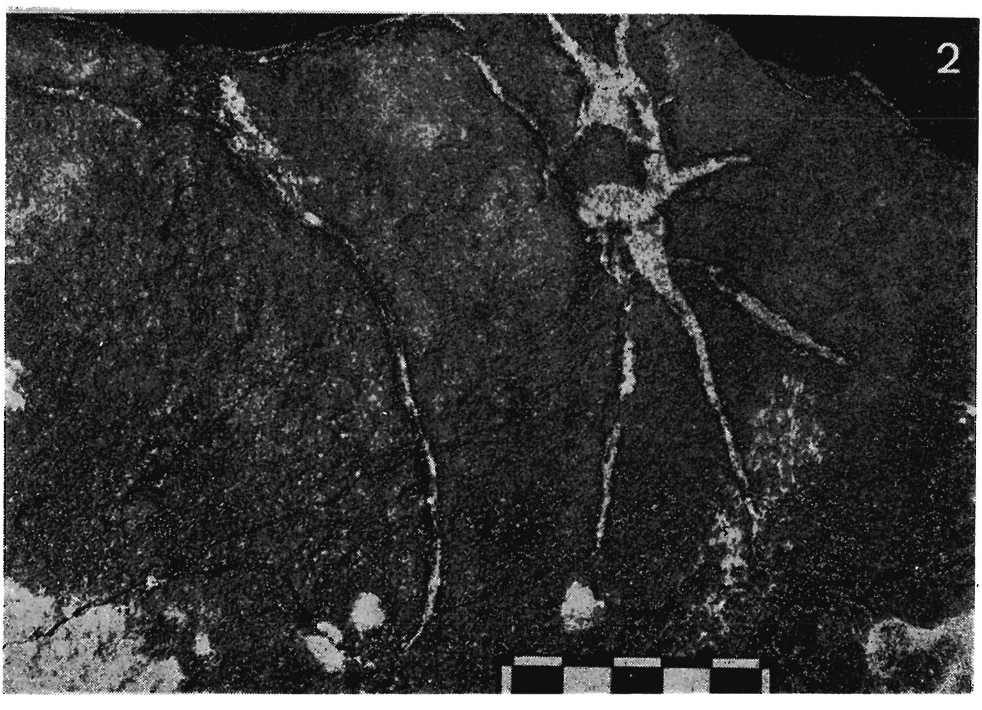
1 — Grooves formed by coarse grains still resting at the endings of the grooves (arrowed), on top of sandstone layer. Association *B*, Ciosowa quarry

2 — Adhesion warts in laminated sandstone (cross-section). Association *B*, Sosnowica quarry

3 — Adhesion warts and adhesion ripple (at lower left) in laminated sandstone. Association *B*, Sosnowica quarry

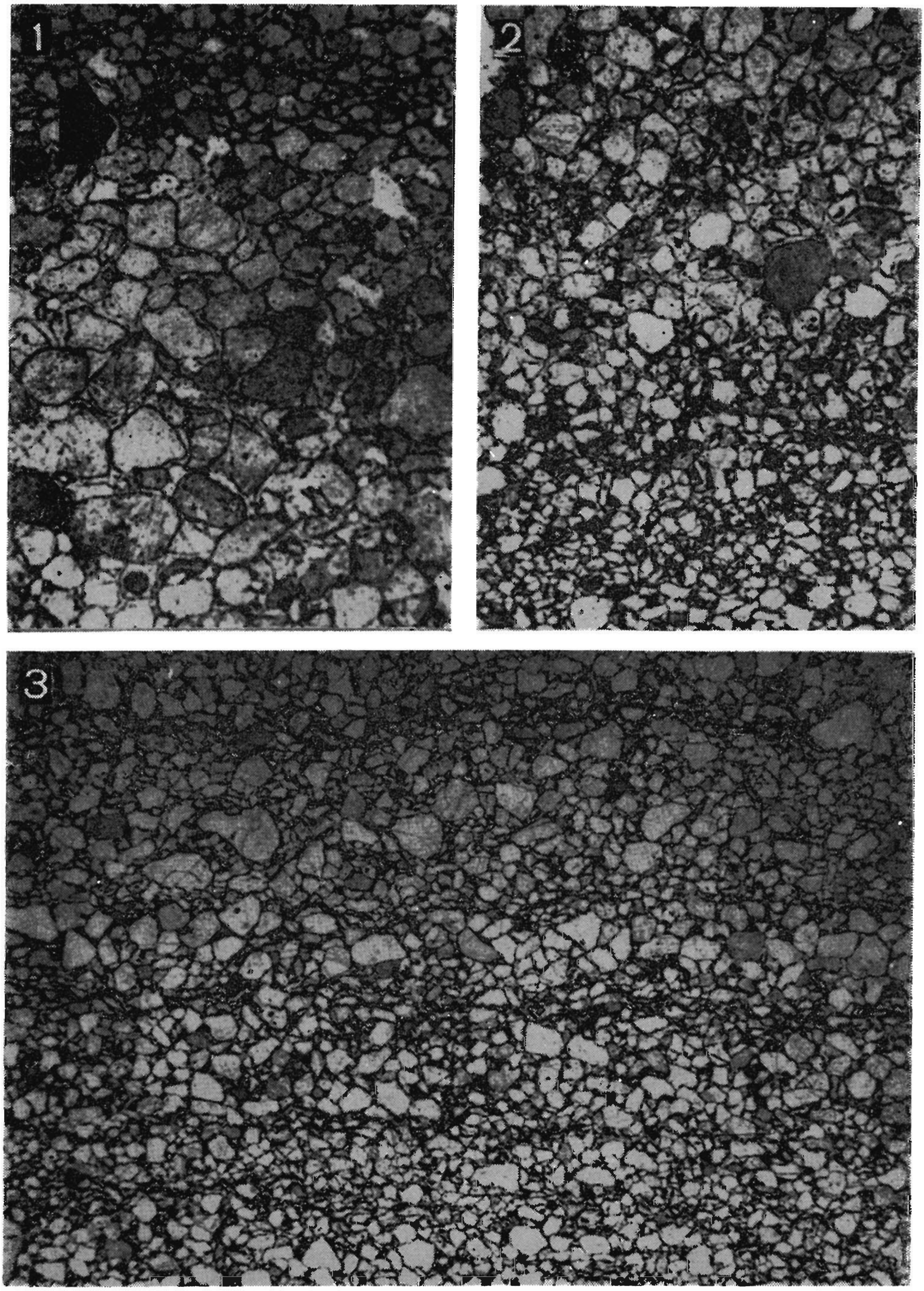
Scales on Figs 1—3 in centimetres





1 — Burrows at surface of sandstone layer. Association *B*, Sosnowica quarry. Scale in centimetres

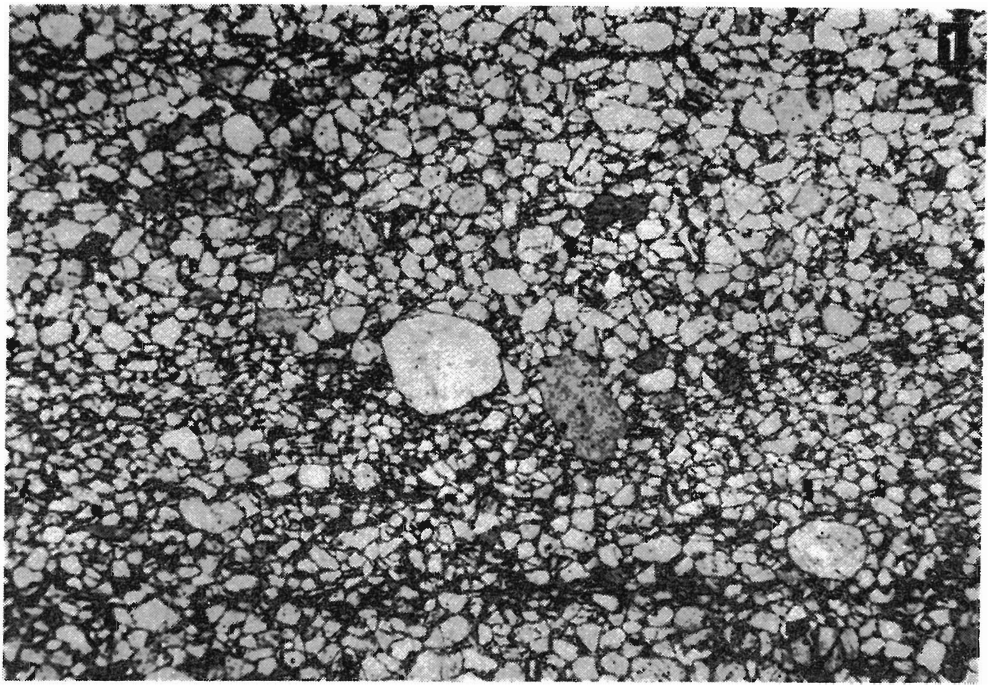
2 — Trace of crawling and radial structure of supposedly organic origin. Association *B*, Sosnowica quarry. Scale in centimetres

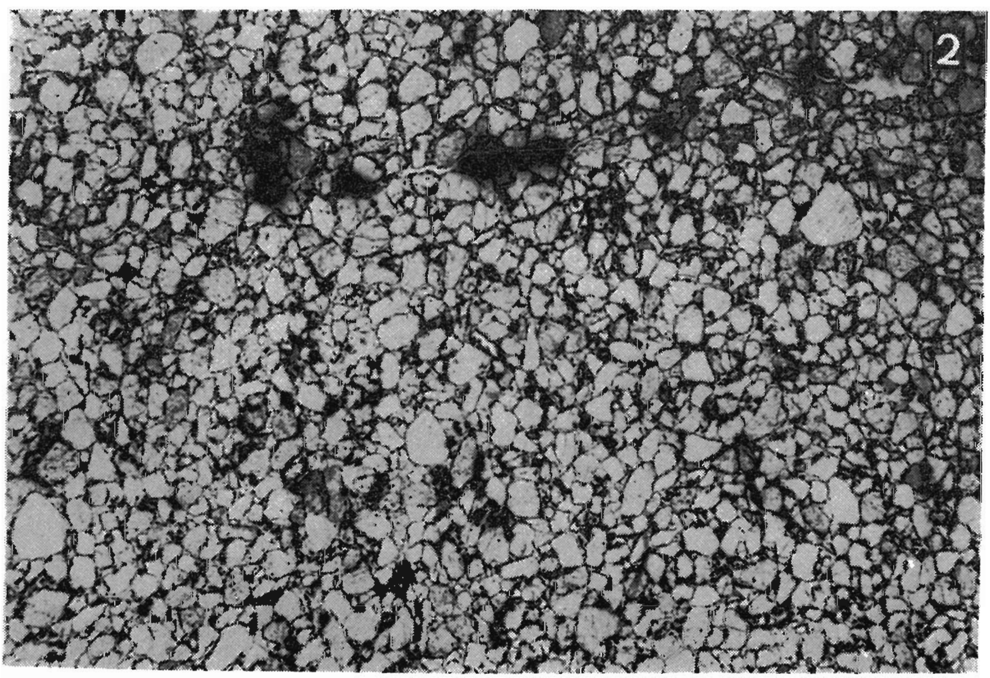


1 — Relatively rapid change in grain size. Sandstone of association *A* (thin section 37), × 16

2 — Gradual change in grain size. Sandstone of association *A* (thin section 37), × 12

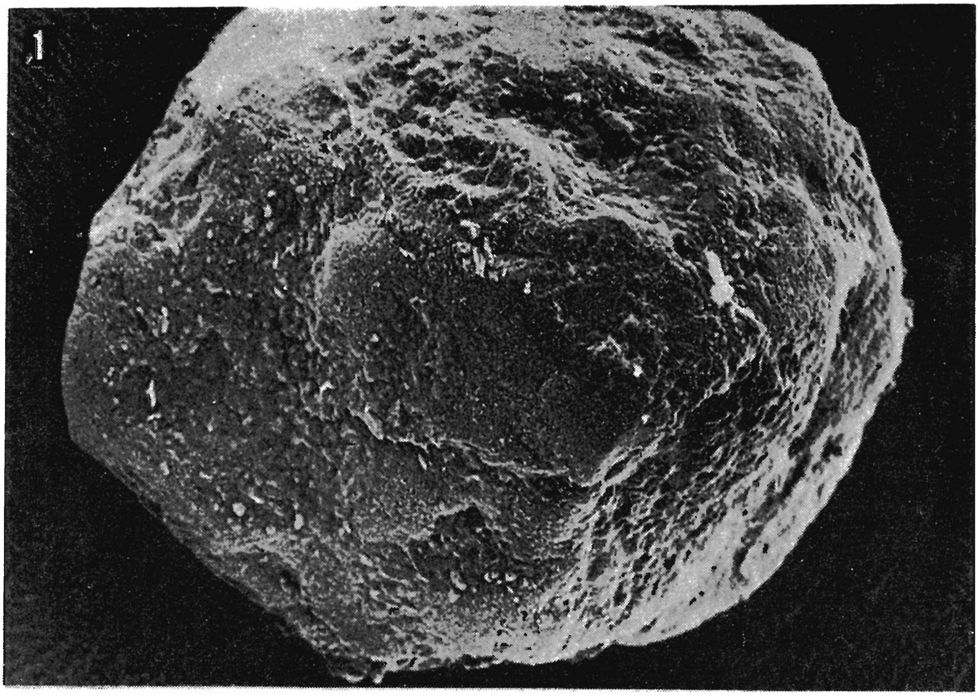
3 — Lamination in sandstone of association *A* marked additionally by thin zones enriched in clayey-ferruginous mass (thin section 41), × 12

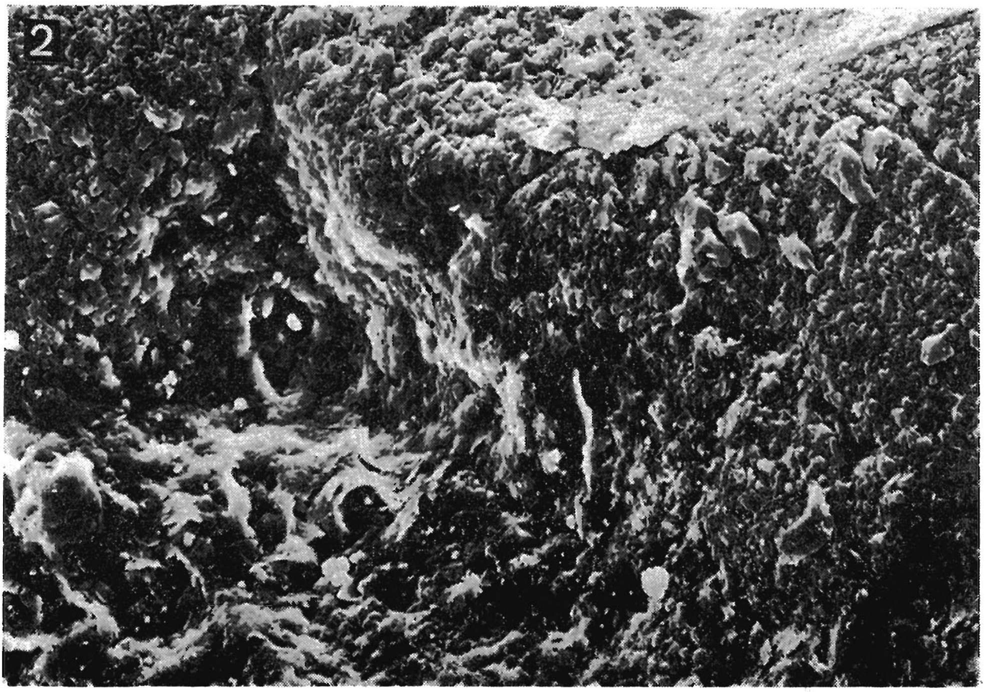




1 — Isolated larger grains in laminated sandstone of association *B* (thin section 49), × 12

2 — Structureless sandstone filling erosional channel (thin section 62), × 12





Scanning electron micrographs: 1 — Quartz grain, × 325; 2 — Upturned plates modified by solution and precipitation, × 1950